Borrower is requisted to check the book and get the signatures on the torned pages, if any.

TWO-WAY RADIO

TWO-WAY RADIO

by SAMUEL FREEDMAN

COMMANDER S(E)T U.S.N.R.

Specialist in Two-Way Radio Planning; Member, Institute of Radio Engineers; Member, Veteran Wireless Operators Association; Member, American Radio Relay League (W1FJS)

ZIFF-DAVIS PUBLISHING COMPANY

CHICAGO · NEW YORK

At the time this book was designed, a Victory Format was used. Smaller type and margins produced fewer pages and permitted a vital saving of paper and labor in its manufacture.

SECOND PRINTING

MANUFACTURED IN THE UNITED STATES OF AMERICA

I Dedicate This Book to the Idea and the Proof that It Is Technically, Financially, and Legally Feasible for Everyone to Enjoy the Advantages of Two-way Radio Communication

FOREWORD

This book describes the mechanics and applications of two-way radio for all forms of fixed, mobile, or portable communications. It is presented in non-mathematical form and in simple language fully understandable to persons using or intending to use such facilities.

It is being published simultaneously with the commencement of a new communications era in which the general public as well as other users may transmit and receive radio signals. The entire radio frequency spectrum, with its present and forthcoming developments, is discussed. This covers all frequency bands between very low and super-high, as established by the Federal Communications Commission. Equipment described ranges from 5 kilocycles to beyond 10,000 megacycles. Also included is a thorough description of induction radio and carrier current communication techniques.

The field has been expanding rapidly as it emerges from wartime applications to peace-time utilization. It is currently opening up a billion dollar field of business for the radio industry as well as over one hundred thousand new jobs during the next five years in the United States alone, exclusive of foreign market possibilities.

This book represents twenty-six years continuous experience in all forms of radio and electronics (1919–1945) as a professional, an amateur, and a Naval Reserve radio specialist officer. During these years the author has been a radio operator, engineer, inventor, author, student, teacher, and consultant of two-way radio facilities. During his twelve years in the United States Naval Reserve, he has advanced in all ranks from Ensign to Commander while specializing in communications and radio-electronics. Between 1942 and 1945 he was in charge of radio-electronics at the United States Submarine Base, New London, Connecticut, followed by a smiliar assignment at the United States Submarine Base, Pearl Harbor, involving both the Atlantic and Pacific Fleets. Prior to mobilization, he was Radio Engineer for the Passamaquoddy Regional Project of the National Youth Administration, establishing two-way radio systems for many public agencies in the State of Maine. Previous to 1939, he was Radio Adviser for the County and Townships

on Cape Cod. Commencing with the Postal Telegraph Company in 1918, he shifted to radio as a ship radio operator with the Marconi Wireless Telegraph Company in 1919. Starting with spark transmitters and crystal receivers, graduating to arc transmitters and later to vacuum tube transmitters and receivers, he has been present during the entire growth of modern radio communication. About 1933, as Activity Manager of the Cape Cod Radio Club, he sponsored ultra high frequency activities, making possible mobile two-way communications on the then so-called "five-meter" band. From there he has constantly experimented or developed systems using higher and higher frequency spectrum. Today he is approaching wave lengths as short as one centimeter or frequencies as high as 30,000,000 kilocycles, with the limit not yet in sight.

In 1935, the author proved the feasibility of two-way radio for the Hyannis, Massachusetts, Police Department, involving 74 square miles of territory. In 1937, he built the Barnstable County Radio System, embracing every public agency throughout Cape Cod in an area containing 355 miles of coast line. In 1940, he designed and supervised the construction of the Maine State Police Radio System, involving 39,000 square miles of territory. The author has been largely responsible for the establishment of more than fifty two-way radio systems. These have been, and still continue to be, in use for police, fire, forestry, sheriffs, prisons, humane societies, fisheries, conservation, the armed forces, and many others.

On May 25, 1945, the Federal Communications Commission legalized for civilian use the new frequency spectrum developed in World War II. This has increased by over three hundred times directly, and by thousands of times indirectly, the channel space available for two-way radio communication. This permits utilizations heretofore impossible or prohibited because of inadequate channel space and unavailable equipment techniques necessary for such high frequency operation. These new uses now include any legitimate communication need particularly railroads, trucks, buses, private automobiles, and all forms of personalized fixed or mobile applications. This is in addition to the previously known services such as police, marine, and aviation radio services. Aiding further in the realization of these new uses is a liberalization in the station and operator licensing requirements by the Federal Communications Commission. That body has fully kept pace with two-way radio possibilities and is due full credit for the conception and establishment of the Citizens Radiocommunication Service.

In compiling this book, diversity of opinion was found to exist with respect to the importance of frequency modulation, microwaves, and techniques for obtaining beyond-horizon ranges. Actually, there is little

to be argued as to their advantages and limitations. It is more in the nature of an argument whether we shall hang on to the old because it represents an investment in existing facilities and techniques which do provide useful communication or whether we shall scrap everything and adopt the new because it is more efficient, more compact, and less expensive either initially or for subsequent maintainence. Where serious differences of opinion arose, the author conferred with many qualified men. Their opinions, where based on actual experiences, were carefully noted before a final determination was made in deriving facts for this book. In most cases, the facts were further confirmed by the personal knowledge and experience acquired by the author in his own undertakings.

Two-way radio is not prohibitive in cost. The author has on numerous occasions in New England built pre-war radio systems for public agencies without an actual appropriation for that purpose. It was accomplished by starting early in an annual or bi-ennial budget period and utilizing in advance the immediate anticipated economies two-way radio could make possible. These economies were always present in the form of improved communication, reduced operating costs, or improved revenues. These are fully enumerated and discussed in this book.

As the two-way radio field expands, the tendency develops for radio manufacturers to merge into larger or more efficient setups in order to serve better large transport customers. Firms listed in this book, even as this book is being completed, may be found to have merged or undergone a change of their corporate name wholly or partially. Current radio magazine advertising should be consulted to keep up-to-date in this connection.

While this book devotes considerable space and frequent reference to the importance of microwaves, it is felt that the subject can be expended further. This is particularly true in view of the fact that much of the new frequency allocations by the Federal Communications Commission lies above 300 megacycles. This expansion has been recognized and will be fully discussed in another book by the same Author entitled *Microwave Communication and Detection.* The latter book not only embraces two-way radio beyond 300 megacycles but also discusses radar for navigation and midar for warnings. Radar and midar are outgrowths of two-way radio ultra high (now called very high) frequency techniques of the past twenty years.

This book could not have materialized without the exceptional coöperation received from innumerable persons, firms, and associations sympathetic to the undertaking. Space does not permit more than merely acknowledging one hundred of the more important sources of assistance received and incorporated herein. The list is by no means complete.

To all of them, the author expresses his sincerest thanks and will always be on the alert for an opportunity to reciprocate the courtesies and help extended to him.

More than forty different manufactured two-way radio equipment circuits and part lists were received by the author for this book. Out of this total number, there have been selected the representative circuits used in this book. These are not the only circuits of their kind nor necessarily the best in some cases. However they are the typical circuits around which the two-way radio field was built and from which it has progressed. It is to be expected that the art will steadily improve in equipment and techniques with time, invention, and competition.

The author's interest and participation in two-way radio continues as his principal specialty. Although this book was commenced before the war, it could not be completed until September, 1945. The entire book has been cleared for publication by the Director of Public Relations of the United States Navy.

SAMUEL FREEDMAN
Commander USNR

ACKNOWLEDGEMENTS

Aireon Manufacturing Co., Kansas City, Kansas.
Allied Radio Corporation, Chicago, Illinois.
American Radio Relay League, West Hartford, Conn. (ARRL).
American Telephone and Telegraph Company, New York (AT&T).
American Trucking Associations, Washington, D.C. (ATA).
Andrews, Victor J. & Co., Chicago, Illinois.
Appleby, Lt. Comdr. Thomas, Patent Division, U.S. Navy.
Armstrong, Major E. H., New York City, N.Y.
Associated Police Communication Officers (APCO).
Association of American Railroads, Office of the President, Washington, D.C.
Association of American Railroads, Communication Section, New York, N.Y.
Atchison, Topeka & Santa Fe Railroad, Chicago, Illinois.
Bakst, Lieut. Myron F., Bureau of Ships, U.S. Navy.
Baltzer, Otto, MIT Radiation Laboratory, Fishers Island, N.Y.
Barnstable County Police Radio System, Cape Cod.
Bell Telephone Laboratories, various individuals.
Bendix Radio Division, Baltimore, Md.
Bonardi, Giusto Fonda, Lieut. Royal Italian Navy.
Budelman, Fred, New York, N.Y.
Browning Laboratories, Winchester, Mass.
Bugbee, Comdr. L. W., Office of Research & Inventions, U.S. Navy.
Burgess Battery Co., Freeport, Illinois.
Burton, Robert R., U.S. State Department.
Chicago, Burlington & Quincy Railroad, Chicago, Illinois.
City of South Portland, Maine.
Communication Equipment and Engineering Co., Chicago, Illinois.
Connecticut State Police, Hartford, Conn.
Courtney, Jeremiah, Federal Communications Commission Legal Department.
Crocker, Sheriff Lauchlan M., Barnstable, Mass.
DeForest's Training Inc., Chicago, Illinois.
Director of Public Relations Office, Navy Department, Washington, D.C.
Doolittle Radio, Chicago, Illinois.
Eastern States Police Radio League, Boston, Mass.
Ehrenhaft, Dr. Felix, formerly Physics Dept., University of Vienna, Austria.
Everett, Professor H. S., University of Chicago.
Fairbanks, W. A., Association of American Railroads, New York, N.Y.
Farnsworth Radio & Television Corporation (Halstead), Fort Wayne, Indiana.

Federal Communications Commission, Washington, D.C.
Federal Telephone and Telegraph Company, Newark, N.J.
Galvin Manufacturing Co., (Motorola), Chicago, Illinois.
General Electric Company; Schenectady, Syracuse and Bridgeport plants.
Greyhound Corporation, Chicago, Illinois.
Hallicrafters, Inc., Chicago, Illinois.
Halstead, William S., Halstead Traffic Communications Corporation, New York, N.Y.
Hansen, Mr., Field Service Group, Columbia University.
Harco Towers, Elizabeth, N.J.
Havery, Clifford A., Southbridge, Mass.
Harvey Radio Laboratories, Cambridge, Mass.
Harvey Wells Communications, Inc., Southbridge, Mass.
Henry, Col. R. S., Washington, D.C.
Highway Radio, Inc. (Trucking Field).
Hoag, Comdr. J. B., U.S. Coast Guard Academy.
Intercity Bus Radio, Inc., (Bus Field).
International Telephone and Telegraph Co., New York City.
Jefferson Travis, New York City.
Joyce, Lt. Col. Temple N., Baltimore, Md.
Kaar Engineering Company, Palo Alto, Calif.
Kahn, Morton B., New York City.
Knight, Comdr. John B., Naval Research Laboratory Annex.
Krebs, William N., Safety Services Division, Federal Communications Commission.
Link Radio Corporation, New York City.
Maine State Police, Augusta, Maine.
Meagher, J. R., Camden, N.J.
Michigan State Police, East Lansing, Michigan.
Microwave Corporation of America, New York and Baltimore.
National Association of Motor Bus Operators, Washington, D.C.
National Association of Taxicab Owners & Cab Research Bureau.
National Carbon Company, New York City.
Neisse, John L., Indianapolis, Indiana.
New York Central Railroad, Telephone and Telegraph Department.
Noble, Dr. Daniel, Chicago, Illinois.
Oehler, A. G., Railway Age.
Onan, D. W. & Sons, Minneapolis, Minn.
Pechman, Herbert, Sterling Factors.
Pioneer Genemotor Company, Chicago, Illinois.
Pollock, Dr. Dale, Templetone Radio Company, New London, Conn.
Premax Division, Chisholm Ryder Co., Niagara Falls, N.Y.
Radio Corporation of America, Dept. of Information.
Radio Technical Planning Board committees.
Railway Express Company, New York City.
RCA Service Company, Camden, N.J.

RCA Victor Company, Harrison, N.J.
Raser, Edward, New Jersey State Police, Trenton, N.J.
Reddington, Lt. Comdr. H.B., U.S. Coast Guard, Groton, Conn.
Sikorsky, Igor T., United Aircraft, Stratford, Conn.
Simmons Boardman Publishing Co., New York City.
Simplex Wire and Cable Co., Cambridge, Mass.
Slote, Edwin M., New York City.
Southern Pacific Railroad, San Francisco, Calif.
Sperry Rail Service, Hoboken, N.J.
Sperry Gyroscope Company, Brooklyn, N.Y.
Stocklin, W. F., Radio News, Chicago, Illinois.
Strongin, Lt. Comdr. H. F., USNR. U.S Navy Medical Corps.
Thomas, L.R., Electronics Engineer, Sante Fe Railroad.
Transmitter Equipment Manufacturing Co., New York City.
Union Switch and Signal Company, Swissvale, Pa.
Upton, Laurence C., Chief, Marine State Police.
United States Patent Office, Washington and Richmond.
Warner, Sydney, Radio Engineer, Connecticut State Police.
Ziff-Davis Publishing Company, Chicago, Illinois.

CONTENTS

LIST OF ILLUSTRATIONS

TWO-WAY
RADIO

CHAPTER ONE

INTRODUCTION TO TWO-WAY RADIO

1 Definition of Two-way Radio

A two-way radio station receives from, and transmits back to, any other similarly equipped stations; it also initiates transmissions and receives replies.

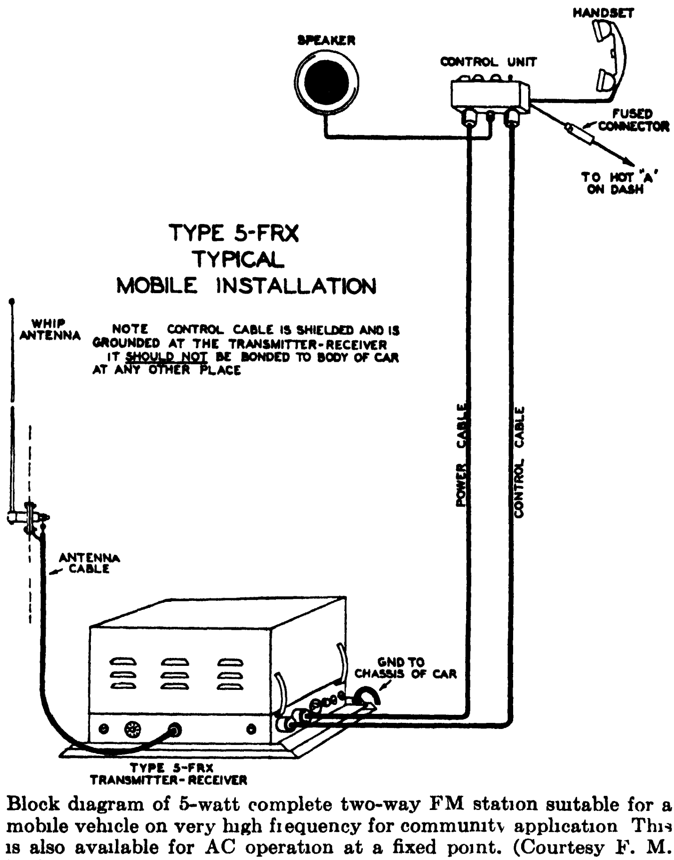
Two-way radio usually means radiotelephone voice communication between stationary and moving radio stations or between movable or moving stations in any combination An example is a roving police car equipped to receive messages from police headquarters and to transmit back to headquarters as well as to other police cars. Two-way radio is usually the only method of communication possible between vehicles in motion, and it can be maintained on the ground, afloat, or aloft.

When the headquarters station has only a transmitter and a vehicle has only a receiver, the equipment comprises a one-way system. If headquarters adds a receiver and the vehicle is provided with a transmitter, the system becomes two-way.

It is possible to have car-to-car communication at the same time and with the same equipment. When a system has this additional leg of communication, it is sometimes called three-way radio. By the same reasoning, when substation communicates with substation, it could be called four-way radio; if walkie-talkie units were included, it could be called five-way. It is erroneous, however, to call these additional legs of communication anything other than two-way radio. This holds true whether the facilities permit car-to-car, substation-to-substation, or similar intercommunication between planes, boats, trains, or portable units. In every case there are only two functions: receiving and transmitting; but there is great flexibility in the use of those functions.

2 Basic Parts of Equipment

Radio is a combination of the effects of electricity and magnetism. The resultant is an electromagnetic wave which can be propagated through space between the transmitting and receiving antennas at a speed of about 186,000 miles per second. This phenomenon is possible because of the very high frequency, even though the power employed may



Block diagram of 5-watt complete two-way FM station suitable for a mobile vehicle on very high frequency for community application This is also available for AC operation at a fixed point. (Courtesy F. M. Link)

be very low. Where ordinary electrical power may have a frequency of 60 cycles per second for alternating current, in the case of radio it may rise to billions of cycles per second, depending on the wave length used. The equipment described in this book, with the exception of induction radio, operates on frequencies not lower than 1,600,000 and as high as 3,000,000,000 cycles per second. As the frequency increases, the power may be reduced.

To provide radio communication, it is necessary to have equipment which can generate, propagate, and receive electromagnetic waves. This is largely accomplished by the following four basic components:

Inductance. A coil of wire through which an electric current flows is a source of inductance. A magnetic field is developed about the coil which induces a current in an adjacent inductance to produce transformer action. A magnetic field moving across an inductance also creates a current flow in the inductance, which opposes a change or collapse of the current flow that gave birth to it. As a result, the maximum current in an inductive circuit occurs later than the maximum voltage for the same circuit. An opposition or reactance to the flow of alternating current is also developed which keeps increasing as the frequency is increased, until in the microwave band it behaves as a virtual insulator to AC. At the same time it continues as a good conductor for DC.

Capacitance. A fixed or tunable condenser, which stores electricity at rest, is a source of capacitance, as the condenser becomes charged when the circuit current exceeds certain values, depending on the dimensions and materials comprising the capacitance. When the circuit potential value is less than that stored in the condenser, the latter discharges back into the circuit to maintain balance.

Resistance or Insulation. The flow of electric current is reduced or stopped by certain materials. German-silver wire and carbon cut down current flow by producing a drop in the circuit voltage. Glass, porcelain, and special compositions stop the flow of current entirely for all practicable purposes, as their resistance is virtually total. Actually there is no perfect insulator or perfect conductor. The best insulator is simply the poorest conductor because it possesses infinite DC resistance. In the case of alternating current, as the frequency is increased to maximum, even the best insulator will conduct or leak.

Vacuum Tube or Valve. Present-day radio communication would be impossible without the modern vacuum tubes which generate and rectify the enormously high frequencies required for two-way communication. Some of the functions of vacuum tubes in radio communication are:

1. Developing very-high-frequency alternating current from a direct current or lower-frequency alternating current. The vacuum tube is then a generator, oscillator, or frequency multiplier. It can develop frequencies a million times greater than the best mechanical generator.

2. Making a small change in its input circuit voltage (such as may result from a feeble signal) produce a major change in its output circuit voltage. It is then an amplifier. Amplifiers can be cascaded until an enormous amplification is reached, limited only by the signal-to-noise ratio existing in the equipment.

3. Converting an alternating current into a direct current, thereby serving as a rectifier.

4. Blending speech or audible frequencies fed to a tube from a microphone circuit with the high-frequency signal that originates in the oscillator for transmission through space. The tube then serves as a modulator.

5. Extracting the audible sounds from a high-frequency electromagnetic wave at the receiving point so that the human ear can respond when a loudspeaker is actuated. It then is known as a detector, demodulator, or discriminator.

With these four basic components any type of radio or electronic device can be created, differing only in the number, size, and manner of connection of inductances, condensers, resistors, and tubes.

It should be remembered that capacitance always behaves exactly opposite to inductance in any radio or electrical circuit. Where the inductance becomes a virtual insulator at microwave frequencies, capacitance decreases in reactance, becoming at that point a virtual conductor to AC, while still remaining a block or insulator to DC. Capacitance makes the current maximum occur sooner than the voltage maximum in a circuit. When the reactance resulting from inductance is equal in ohms to the reactance resulting from capacitance, they cancel, and the circuit is in tune, and maximum energy transfer occurs.

Resistance causes a voltage drop which reduces the current flow in a circuit. The vacuum tube controls the polarity or phase of an electric current or potential, so that the current may flow, stop, or act in any variable or other manner required.

3 How Two-way Radio Functions

In two-way radio a transmitter generates a very-high-frequency alternating current of constant frequency and amplitude called the radio-frequency carrier. This carrier wave has a frequency which depends on the circuit component sizes and connections. A typical frequency might be 39,900,000 cycles per second and a velocity of 300,000,000 meters per second. It is desired to have this frequency convey the voice of the announcer to the ear of the listener many miles away aloft, afloat, or on land. The sound uttered by the announcer may be only a few hundred cycles per second in frequency. Its rate of travel in air is only about 1100 feet per second.

The process of making the carrier wave accept sound is called modulation. The sound-pressure wave striking the diaphragm of the microphone causes vibrations which result in electrical variations in the microphone circuit. When these variations are made to change the amplitude of the carrier wave, it is known as *amplitude modulation* or AM; when made to change the frequency of the carrier wave, it is known as *frequency modulation* or FM. It may also be called phase modulation or PM.

The modulated carrier wave is propagated through space by an antenna connected to the transmitter through some suitable transmission line. The electromagnetic waves in space, propagated as the modulated carrier energizes the antenna, maintain a constant speed of 186,000 miles per second, but diminish in intensity in free space approximately as the inverse square of the distance. Any antenna lying in the path of these electromagnetic waves has induced into it a small voltage, which for good equipment can be less than one-millionth of a volt (one microvolt). This voltage causes a feeble current to flow through the receiver to ground. If the frequency of this current corresponds to the values and settings of the receiver circuit components, it energizes the receiver, which otherwise is in standby condition.

4 Frequency and Wave Length

The establishment of new two-way radio facilities involves three problems:

1. Finding channels that are available and free from interference.
2. Finding equipment that can function on such channels.
3. Designing the system so that satisfactory coverage is realized with the available channels and equipment.

Wherever possible, new utilizations should not be attempted on experimental license, unless it appears certain that a permanent channel license will be granted when tests prove successful. In the past, railroads have had successful tests on very high frequencies, using police radio equipment on experimental license for a temporary period, but they could not retain the channel license, because the channels sought were overcrowded or already allocated to prior users in important emergency services. It is therefore important that railroads and commercial and private applicants, requiring exclusive channels, seek them in new or uncrowded parts of the radio-frequency sepctrum. With the exception of limited relief in the induction radio field, ultra high frequencies and super high frequencies, otherwise known as microwaves, must be used.

Radio waves travel through space at the rate of 300,000,000 meters per second. This corresponds to the speed of light or 186,000 miles per second. A meter is 39.37 inches or 3.28 feet long. These invisible waves have a frequency and a wave length. The distance between any two identical points of adjacent waves, such as crest to crest or valley to valley, is called the wave length and is expressed in meters. The number of these waves or vibrations is called the frequency. Frequency is expressed in cycles per second. If the number of cycles is large, as is the case of short waves, it is expressed in kilocycles or megacycles. A kilocycle is 1000 cycles. A megacycle is 1,000,000 cycles, or 1000 kilocycles.

The laws of physics and science are not violated when frequency and wave length are changed, so long as the velocity of 300,000,000 meters per second in air is not changed. The number of waves per second multiplied by the length of each wave must equal 300,000,000. Only by changing the medium from air to something more or less dense can there be a velocity other than 300,000,000.

It follows, therefore, that the longer the wave length, the lower the frequency; the shorter the wave length, the higher the frequency. The ratio is uniform and consistent. It follows the formulas given below, based on 30,000 kilocycles or 10 meters.

$$\begin{array}{l}\text{Velocity} \\ \text{in meters} \\ \text{per second}\end{array} = \text{Wave length} \times \text{frequency} = 10 \text{ meters} \times 30{,}000{,}000 \text{ cycles} = 300{,}000{,}000 \text{ meters per second.}$$

$$\begin{array}{l}\text{Wave length} \\ \text{in meters}\end{array} = \frac{\text{Velocity}}{\text{Frequency}} = \frac{300{,}000{,}000}{30{,}000{,}000} = 10 \text{ meters.}$$

$$\begin{array}{l}\text{Frequency} \\ \text{in cycles} \\ \text{per second}\end{array} = \frac{\text{Velocity}}{\text{Wave length}} = \frac{300{,}000{,}000}{10} = 30{,}000{,}000 \text{ cycles per second.}$$

30,000,000 cycles can also be expressed as 30,000 kilocycles or 30 megacycles.

The signal generated in a transmitter has a wave length and a resultant frequency which depend on the dimensions, materials, spacing, and interaction of the inductance and capacitance in the circuit. Inductances and capacitances need not be actual coils or condensers; they can be materials which provide an equivalent effect. A wire by itself has inductance. The space between two wires, or between a wire and a ground, is equivalent to a dielectric with the two wires, or the wire and the ground, forming the plates of a condenser. The effect of inductance and capacitance is always present. On microwaves it may comprise little more than the effect of the components and their space separations in a tube, but it continues to be present. The parts behave as follows with respect to wave length and frequency:

1. More inductance increases the wave length and reduces the frequency when in series with a circuit.
2. More capacitance in series tends to reduce the wave length and increase the frequency.
3. More capacitance, when connected in shunt or parallel to an inductance or another capacitance, raises the wave length and reduces the frequency of the circuit.

As the wave length becomes shorter or the frequency greater, the parts become smaller in dimension, until in the microwave band they begin to approach microscopic dimensions. It then requires new techniques, some of which have the greatest advantages and possibilities

for two-way radio communication. These new techniques include tubes of special structure to overcome situations where the transit time is longer than the period of oscillation, the electron grouping principle where the transit time is made to correspond to whole or fractional periods of oscillation, resonant cavities for tuning, and wave guides for transmission lines and antennas. Low-frequency conceptions and techniques should not be used in dealing with frequencies higher than 1000 megacycles. This corresponds to wave lengths shorter than 30 centimeters.

5 Channel Space

The number of stations that can be accommodated depends on:

1. Whether many stations and setups share a common frequency. This is usually the case on low frequencies. For example, four state police departments are expected to share one channel for their medium-frequency operations.
2. Whether amplitude modulation, using 10 kilocycles per channel, or frequency modulation, using 40 kilocycles or more per channel, is employed.
3. Whether voice or music is to be transmitted, and to a minor degree whether the voice is masculine or feminine, bass or tenor. For FM, the Federal Communications Commission allocates five times more channel space to handle music than for voice.
4. Which part of the spectrum is being utilized. There is more channel space on the shorter wave lengths than on the longer wave lengths. Between 30,000 meters and 1 meter in wave length, there is a total frequency difference of only 300,000 kilocycles. Yet on the microwave band between 1 meter and .1 meter lies a frequency difference of 2,700,000 kilocycles. Each station requires a minimum number of kilocycles regardless of the wave length employed.

It follows therefore that the shorter the wave length, the more stations can be accommodated, because the frequency spectrum is much greater there. The Federal Communications Commission has determined that 10 kilocycles is the minimum separation per station for amplitude modulation; 40 kilocycles is the minimum for FM voice; and 200 kilocycles the minimum for FM music. This is not too much, since the human ear responds to frequencies that may exceed 15,000 cycles per second maximum.

By using very high or super high frequencies, the FCC may see its way clear to permit channels of more than minimum separation to improve transmission of sound by radio and to prevent overlapping or interference between stations on adjacent channels. Stations sharing medium- or low-frequency channels have difficulty, even though separated. For example, on 1642 kilocycles, Maine, Michigan, Arkansas, and Wyoming have the same state police frequency. They have the equivalent of clear channel frequency during day operation but interfere with each other during nighttime when the ionized layers are higher above the earth. At such times the sky-wave component of the radio transmission

hops a larger distance before returning to earth. Maine hears Michigan at night louder than its own stations, and vice versa. Occasionally Arkansas contributes to the interference with Maine.

6 Sky Waves and the Ionosphere

Radio waves travel to distant areas by two paths, called sky waves and ground waves. The sky wave travels an indirect path, bouncing along between the earth and the ionized layers above the earth. The ionized layers tend to reflect at least part of the signal back to earth by leaps and bounds, which become greater as the frequency is increased, until a critical frequency is reached beyond which the signal will not return to earth, even on the first hop.

Above the earth are several ionized layers, the lowest of which is about 50 miles, while other layers are known to exist for 200 to 500 miles or more above the earth. These layers increase in height at night. They are lowest in summer during the morning and are highest in winter at night, with the result that the critical frequency is lowest in winter at night and is highest in summer between daybreak and noon.

This is demonstrated on the short-wave broadcast listening band. In the eastern part of the United States, European broadcast stations give their best performance on 19 meters in the morning, 25 meters in the afternoon, 31 meters in the evening, and 41 meters late at night. After midnight in the United States, when Europe is having daylight, there is fading and wavering, as waves are received by many paths, some clear around the world in many different directions. In the marine service, Cape Cod, Massachusetts, has been able to work at 8 a.m. with Australia, on 18 meters; with Bombay, India, in the afternoon on 24 meters; with Little America near the South Pole in the evening on 36 meters; and on shorter wave lengths during the day. By utilizing sky waves on the short-wave band, the Border Patrol has been able to communicate from Maine to Oregon from mobile installations, although the normal ground wave might only be 50 to 100 miles. It is a function of frequency rather than power. The higher the frequency, the less power and greater range is possible until the range becomes so great that the signal misses the earth entirely because of its resultant angle of reflection from the ionosphere.

Because of the nonuniform performance of sky-wave operation, as well as excessive coverage with skip distances in between and the tendency to pick up static or other undesired noise from great distances, sky waves are not ideal for two-way radio communication. They are not clear channels, and, because of their limited number, many stations have to share one channel. They also are not available for FM because of limited channel space. Sky-wave communication is useful principally where

skilled full-time personnel and multichannel equipment are available, so that operations can shift to increasingly longer wave lengths as the time of day changes. Sky-wave communication is not recommended where uniform coverage is required from a single point beyond the horizon and where the frequency is fixed. Sky waves are superb for clearing high mountains, as the highest mountain is very small when compared with the height of the ionized layers. On low frequencies, curtailment or reduction of operations is inevitable for periods each day during the static season, particularly in the tropics or during an approaching storm several hundred miles off.

7 Ground Waves and Curvature of the Earth

All radio waves have a ground-wave component that is influenced by the curvature of the earth. The same component is responsible for the conducting paths in space where there is no dependence on reflections from the ionized layers. The communication obtained from the ground-wave component is dependable and consistent as far as minimum working range is concerned.

On wave lengths capable of sky-wave reflections from the ionized layers for earthly distances, the ground-wave component may be as much as 1000 miles on the very low frequencies when backed by maximum power. This ground-wave range decreases as the working frequency is increased, until at the threshold where sky waves have return bounces that exceed the maximum dimension of the earth, a minimum range of slightly more than the optical horizon is reached. But this horizon theory is defective, as the range can be definitely exceeded. Today, many systems experience dependable performance for ranges equivalent to two or more horizons. On frequencies having no useful sky reflections, namely ultra high and super high frequencies, which currently are not less than 30,000 kilocycles and extend to 30,000,000 kilocycles and beyond, it is no longer correct to limit the predictable range to the optical horizon.

It has been regularly observed that ground-wave ranges for more than horizon distance are attainable under one or more of the following conditions:

1. If the signal-to-noise ratio is kept favorable, so that the received signal, which falls off rapidly beyond the optical horizon but is still present, can be amplified to a suitable level through vacuum tube amplifiers in the receiver.
2. If frequency modulation is used instead of amplitude modulation, the receiver has a much better signal-to-noise ratio and is therefore able to stand much more amplification.
3. If the antenna system is properly cut for the frequency employed and has a transmission line leading to it which does not produce standing waves that radiate instead of, or in addition to, the antenna.

4. If the carrier wave is made to vary in frequency modulation an amount equal to the full natural band-pass of the receiver used to pick up such signals.

5. If the conductivity of the earth and of the space between the earth and the atmosphere for the heights required for aeronautical communication has been increased by the presence of moisture or other conducting mediums.

6. If the wave can travel through areas of mud, marsh, bog, rain, snow, sleet, ice, fog, dew, water, haze, mist, clouds; also if these areas are not arid and are not of dry sand, rock, or magnetic ore. Winter and spring conditions are better because of the snow and rain, and conditions are better at night because there is less aridity than in the day.

7. If there are conducting guides from the transmitting to the receiving point, such as railroad tracks, wayside wires, wayside reflectors, suitable terrain contours, or the like.

8. If the antenna radiates in a narrow beam instead of in all directions, more power is available for the desired lane of communication.

8 Computing Probable Range

The designing engineer should first find out whether the optical range includes the entire area to be covered. This is usually the case in a small city or town, and then it is easy to provide reliable 100 per cent coverage. The equipment, modulation, amount of power for each unit, and so on, can be of the simplest and least expensive type, and results can be attained on any available frequencies.

If the required range exceeds the optical horizon, or if hills, valleys, curves, canyons, gorges, or high structures block the line of sight, it is necessary to analyze all the factors that improve ground-wave communication range beyond the theoretical horizon.

A hill or mountain is frequently an advantage rather than a disadvantage for two-way communication. The mobile station may be traveling atop or part way up that elevation. Both the fixed station and the mobile station contribute to the horizon ranges. Each has a computable horizon which adds to the other.

The cheapest way to increase the range is to elevate the antenna at either the transmitting or the receiving point or at both. If, for example, an area lacks 100 feet elevation to clear the horizon, the elevation can be provided at the transmitting or at the receiving point, or can be divided between the two in accordance with the following formula.

The optical horizon is $1.225\sqrt{\text{height of observer}}$ plus

$$1.225\sqrt{\text{height of the observed.}}$$

The radio horizon is computed the same way, but instead of 1.225 for the curvature of the earth, evaluate the factors which increase the range and use a figure not less than 1.4 and, as a rule, not more than 2.0. It can, however, exceed 2.0 under exceptional area and moisture conditions.

Most computations are made from sea level or from the base level for a countryside. In practice there is always more height than that. Only a submarine barely emerging its periscope a fraction of an inch would be at sea level. The height of the vehicle or individual, the height of the antenna, small or simple as it may be, atop the vehicle, the natural elevation of the ground at that point, all increase the horizon several miles. The first few feet of height are most important and provide much more range in proportion than twice that height would provide.

For example, here is a comparison of the computations to obtain the optical horizon and the minimum radio horizon of a car parked near an ocean beach—that is, close to sea level—and its headquarters station in town. The figures used are merely illustrative.

Heights for Car	Feet	Heights for Headquarters	Feet
Height of road above actual sea level	$1\frac{1}{2}$	Height of land where building stands	29
Height of car antenna above road level	$7\frac{1}{2}$	Height of building above the land	40
Total height	9	Height of mast on roof	25
		Height of antenna on mast	6
		Total height	100

Formula:

Optical horizon $= 1.225\sqrt{\text{height}}$ $= 1.225 \times$ square root of $9 = 1.225 \times 3 = 3.675$ miles.

Headquarters optical horizon $= 1.225 \times$ square root of $100 = 1.225 \times 10 = 12.25$ miles.

Total optical horizon between top of car antenna and top of headquarters antenna is equal to 3.675 plus 12.25 = 15.925 miles.

To obtain the minimum radio horizon, use the constant 1.4 instead of 1.225. This gives the car a radio range of 4.2 miles and the headquarters 14 miles. Total 18.2 miles instead of 15.925 miles. Using FM and good areas of conductivity, a constant of 2.0 is attained, which makes the car range 6 miles and the headquarters range 20 miles. Total range 26 miles. Such ranges are frequently exceeded in two-way radio communication by police departments today.

A plane communicating with a boat at sea is an example of very favorable conditions, particularly when frequency modulation is used on very high frequencies. The plane has height to create a maximum horizon. The boat has conditions of excellent ground conductivity, particularly in salt water. An illustration follows:

Plane	Feet	Boat	Feet
Height aloft	6400	Height of antenna above water level	64

Plane: Optical horizon $= 1.225\sqrt{6400} = 1.225 \times 80 = 98$ miles.
Minimum radio horizon $= 1.4 \times 80 = 112$ miles.

Boat: Optical horizon $= 1.225\sqrt{64} = 1.225 \times 8 = 9.8$ miles.
Minimum radio horizon $= 1.4 \times 8 = 11.2$ miles.

Total maximum optical distance = 107.8 miles.
Total minimum radio range = 123.2 miles.

Even with low-powered equipment, the radio range would unquestionably be much greater than that shown, because of the ideal clear path. Note the importance of the first few feet of height. It is logarithmic rather than linear in nature. The height of 64 feet gives a radio horizon of 11.2 miles. Yet 100 times that (6400 feet for the plane) increases the range only 10 times.

An error frequently made in the radio profession is to combine the heights of the transmitting station and the receiving station, and then to work with that single figure; for example, using $1.225\sqrt{6400 \text{ plus } 64}$. That would compute 1.225×80.4 or a total optical horizon of only 98.49 miles. Such a computation makes little allowance for the height of the lesser station. It is particularly erroneous when the stations have heights closer than those used in the example above.

CHAPTER TWO

TWO-WAY RADIO PLANNING

1 Preliminary Considerations

In planning facilities for two-way radio, the following must be considered: (a) area of operations; (b) size and type of communication system; (c) frequency and wave length; (d) range and cost of equipment; (e) equipment components; (f) methods of purchasing; and (g) licensing requirements for the equipment and personnel.

Equipment life, other than normal replacement and repair, is ordinarily unlimited, but obsolescence of two-way radio equipment is probable within any ten-year period, long before it has worn out. Obsolescence will not necessarily be due to failure of the equipment to render useful service; it will be because better results have become attainable within that period. For example, the development of frequency modulation and equipment suitable for microwave frequencies makes equipment for amplitude modulation and low frequencies have a tendency to obsolescence. However, amplitude modulation and low frequencies still function, and such equipment in many cases will continue in use for many additional years.

2 Area of Operations

An experienced radio engineer can plan two-way radio for a small city or community in a few minutes, merely by standing at some high point and glancing over the area. Very short distances, involving less than one mile, require little planning, since virtually any frequency and any power equipment functions well for short distances. It is then rarely necessary to worry about high buildings or hills that ordinarily might be obstacles to communication. For short distances, obstacles can be worked around, through, or over, due to reflection and dispersion effects. The main portion of a radio signal follows laid-out rules; but what the remainder does depends on minor lobes, backward and sideward radiation, and reflections in a manner comparable with the behavior of a beam of light and a mirror. While this small remainder has only a tiny fraction of the power radiated in the main lobe, it does not take very much to cover the first

mile of range, as the radiation field is only commencing to diverge. A modern receiver responds to a field strength of a millionth of a volt per meter of area. Even the smallest equipment rated less than a tenth of a watt can meet that condition.

For areas larger than can be scanned by a person standing at some single prominent spot, much information is obtainable offhand from maps and by traveling over representative areas covered by a certain system. In this regard, standard highway maps are very useful. A good part of the United States has been mapped by the U.S. Geological Survey, Department of the Interior, by polyconic projection. This work, begun in 1882, covers about 50 per cent of the United States to date. The maps measure $16\frac{1}{2}$ inches by 20 inches and use a scale of 2 inches per mile for important areas; 1 inch per mile for areas of less importance; and 1 inch per 2 miles for areas of minor public importance. Contour levels, bodies of water, highways including minor roads, forestry areas, and so on, are shown. The specific height of bodies of water above sea level is indicated as well as the maximum elevation of important hills and mountains. These standard topographic maps for particular areas or states are usually procurable in book and stationery stores. A typical map for the state of Maine covers 15 minutes of latitude and 15 minutes of longitude, or about 200 square miles. Such a scale is suitable for most radio-planning purposes.

By observation or by the use of maps, together with information furnished by the agency desiring the facilities, the following facts should be obtained:

1. Distances in all directions.
2. Topography of the entire area to see how the horizon will clear and by how much more or less than 1.225 times the square root of the elevations for the area.
3. Geology of the area to get some idea of the ground conductivity and thereby determine whether the minimum or maximum constant can be used in the range computation formula.
4. Location of all fixed stations: whether they can relay for each other to and from mobile units on occasion, such as sky-wave operations at night where a distant station comes in better than a local one on low frequencies.
5. Zones where mobile stations will operate: whether they will be on terrain high enough to increase materially the combined horizon, as is usually the case.
6. Areas where mobile stations will not have occasion to operate and for which no special consideration need be given, except where there may be interference with the horizon to a distant point.
7. Optical paths and obstructions that might develop between two stations; whether they are likely to be encountered under ordinary conditions of operation and need to be overcome. Determine these on the basis of (a) curvature of the earth, (b) elevations, and (c) obstructions.
8. Portion of operating area comprising land.
9. Portion of area comprising water.

10. Amount, extensiveness, elevation, and location of hilly and mountainous land.

11. Locations of bodies of water: whether they are salt or fresh or vary greatly with tide or season; whether they are permanent, temporary, or erratic in their presence (for example, the Bay of Fundy tides as encountered in northeastern Maine, or high and low water on the Mississippi River). Also river beds that go dry entirely several months a year. Whether this water exists as lakes, rivers, bays, coast line, inlets, or tidal flats.

3 Communication System

A system is usually started on a modest scale; even a comprehensive system inevitably grows. No system should be planned without provision for expansion, even though it is not always required by the original licensee. It frequently becomes necessary to assist other organizations and other activities that have something in common with the licensee, or a need for additional facilities arises after the system is organized.

Details to be considered are:

1. Number and location of the control stations or headquarters.
2. Number and location of substations.
3. Type, number, and operating areas of portable and mobile stations.
4. Whether relay stations or remote control stations must be provided to keep the equipment away from the dispatching or administrative headquarters, or to get the performance possible on a mountain top from an office located in the heart of the business district.
5. Number of legs of communication. These can be any or all of the following:

   (a) Headquarters to any portable or mobile unit.
   (b) Any portable or mobile unit back to headquarters.
   (c) Any portable or mobile unit to any other portable or mobile unit.
   (d) Any headquarters or substation to any other headquarters and/or substation.
   (e) Walkie-talkie or personalized facilities operating in conjunction with any of the above.

6. Whether all the equipment should operate on a common frequency. This is called simplex operation. All stations hear all transmissions. It simplifies car-to-car communication or the equivalent in addition to communication between headquarters and the car. Generally, simplex operation is simpler, cheaper, and more dependable for intercommunication. It conserves channel space, since one frequency suffices for everyone. Mobile stations on detached services can act independently or as relays without complications, since they are already on the correct frequency. Simplex requires only one antenna-matching consideration.

7. Whether all the equipment should *not* operate on a common frequency, and instead use duplex operation. This provides some privacy; only one leg of the two-way communication is heard on a frequency. Duplex operation simplifies special hookup with domestic telephone lines, which work duplex. It permits interrupting the transmitting station's conversation. It involves two antenna considerations instead of one and requires two frequency channels instead of one. Car-to-car or nonheadquarters stations cannot communicate with each other

directly except by very special or additional equipment and technical provisions; they are dependent on the headquarters station always being in operation and available. Beyond headquarters range, duplex would be partially useless for remote mobile units, which otherwise could relay through intervening located mobile units on the same channel. In duplex operation, every user is not fully cognizant of all communications in the system. Duplex requires careful design and frequency selection, so that transmitter and receiver at each station do not interfere with each other.

4 Frequency and Wave-length Selection

Frequency and wave-length selection depend in part on what the Federal Communications Commission authorizes. The FCC is influenced by the number of applicants for a desired channel as well as by the amount of usage. When an unusual wave length or utilization is involved, the FCC may require proof that the applicant has the equipment and technical skill to justify a frequency allocation.

The Federal Communications Commission, as of March 2, 1943, reclassified the channel designations. They now are known as:

Very low frequency (10 to 30 kilocycles) VLF.
Low frequency (30 to 300 kilocycles) LF.
Medium frequency (300 to 3000 kilocycles) MF.
High frequency (3,000 to 30,000 kilocycles) HF.
Very high frequency (30,000 to 300,000 kilocycles) VHF.
Ultra high frequency (300,000 to 3,000,000 kilocycles)UHF.
Super high frequency (3,000,000 to 30,000,000 kilocycles) SHF.

For radio-planning purposes, it is sufficient to consider these designations in four categories.

Low Frequencies or Long Wave Lengths. On low frequencies, the ground-wave component has a range that may extend considerably beyond the horizon. The sky-wave component returns to the earth before the ground wave has terminated, resulting in consistent operations during daytime only. At night the sky wave does not return to the earth before the ground wave has become too weak for further utilization, and there is a skip area between where the ground wave ends and the sky wave is usable. Frequently that point is outside and beyond the desired zone of communication, and for that reason interferes with ground-wave and even sky-wave operations of stations many hundreds of miles away.

Because the dimension of an ideal antenna has some relation to a quarter or a half of a wave length, an antenna actually might be several miles long for ideal performance; but that, in turn, would not be very effective unless backed by sufficient transmitter power. The low frequencies are very susceptible to static and atmospheric disturbances which often during summer months stop operations completely or nearly

so for hours at a time. The equipment is of large dimension for a given power as compared to higher frequencies.

High Frequencies or Short Wave Lengths. On high frequencies, the ground-wave component has a range that is less than on low frequencies but greater than on ultra high frequencies. The sky wave returns to earth only after a considerable distance beyond the termination of the ground wave at any time, the distance being greatest at night. Between these areas nothing or little can be heard. This skip distance is minimum at dawn and may become thousands of miles at night, increasing as the frequency increases. This skip effect makes possible worldwide communication on low power with quite compact equipment. At certain hours of the night, the skip distance on the higher frequencies becomes so great that they are lost on earth.

The antenna on high frequencies is of moderate or reasonably small dimension. Insulation and design need to be better than for low frequencies. Static is rarely troublesome except at the low-frequency end. Interference from stations thousands of miles away on the same frequency, often involving foreign countries, is heavy. Beamed transmissions, while helpful, may cause interference by encompassing the globe and coming back again, conceivably for several trips around the earth, by multiple bouncing between the earth and the ionized layers.

Very High Frequencies or Very Short Waves. This category now embraces wave lengths between 1 and 10 meters, corresponding to frequencies between 30,000 and 300,000 kilocycles (classified as ultra high frequencies or ultra short waves before March 2, 1943). On very high frequencies, the ground-wave component of a signal is the only usable part, except during rare occasions at the lower-frequency limits, where sporadic reflections may occur from an ionized cloud that might form in space. The sky wave fails to return to earth. As it penetrates the ionized layers, it is bent and also may be at such an angle that it cannot possibly get back to earth within the diameter of this planet.

The antenna is of small dimension, being a vertical type, so that it will operate best at the earth's surface, or a directional beam for sector communication. Power is not too important because of the frequency. Maximum antenna height is required for maximum range. This category is widely used in mobile installations and for general two-way communications. The range to be expected is in accordance with the horizon formulas explained in Chapter One. Ranges of 10 miles are usually simple; 25-mile ranges are not difficult to plan. Greater ranges require careful planning because of the advantages and disadvantages present in any area and system.

Ultra High Frequencies or Microwaves. This category is destined

for great growth. It will be the most interesting field until it becomes more fully occupied and the next spectrum, probably infrared, becomes available. For practical purposes, this band has unlimited channel space, since a small difference in wave length represents an enormous difference in frequency. Wave length affects the dimension of the equipment components, but frequency determines the number of channels and whether they will be of ample space or small and congested.

In the past, microwaves comprised wave lengths shorter than 1 meter or frequencies higher than 300,000 kilocycles. For example, from infinite wave length down to 1 meter there are only 300,000 kilocycles. Between 1 meter and 1 centimeter (a hundredth of a meter) lie 29,700,000 kilocycles or 77 times more room. In addition, these channels are available again about every 50 miles, depending on horizon ranges, much the same as on very high frequency.

Microwaves require new techniques. Such techniques have interesting aspects which are not feasible for lower frequencies.

5 Range and Cost

In general, for the spectrum as a whole, operating ranges depend on:

1. Frequency or wave length employed and behavior with respect to:
   - (a) Usable ground-wave component.
   - (b) Usable sky-wave component.
   - (c) Sky-wave component not available during hours of daylight.
   - (d) Sky wave component not available during hours of darkness.
2. Type and height of antenna.
3. Conductivity of the earth.
4. Efficiency of the receiver in terms of sensitivity rather than merely selectivity.
5. Employment of frequency modulation rather than amplitude modulation where feasible.
6. Use of focused or beamed transmissions aimed at the desired sector of communication without wasting power for the remainder of the earth's sphere.

Equipment costs depend on the following factors:

1. Type and power of transmitters.
2. Type and selectivity of receivers.
3. Frequency measuring equipment.
4. Test and maintenance equipment.
5. Type and nature of control facilities.
6. Equipment furniture.
7. Spare parts.
8. Type and size of antennas.
9. Type and height of masts.
10. Type and length of transmission lines.
11. Real estate and right of eminent domain.

12. Whether relay stations and remote control locations are required. Whether connecting landlines are necessary, or a radio relay link.

13. Whether power to operate the equipment has to be locally generated.

14. Whether auxiliary facilities to produce power and continue operations during emergencies are included.

15. Regular and emergency power supply facilities.

Maintenance costs depend on:

1. Frequency of reinstallation in mobile units.
2. Vacuum tube replacements.
3. Replacement of cables and defective equipment components.
4. Special operating and maintenance personnel, if any.
5. Minor supplies such as solder, tape, small hardware, and the like.

Maintenance costs for equipment replacements can be kept to a figure that may be virtually nothing in some years. The average for more than 20 two-way radio setups used by police and fire departments in Maine and on Cape Cod in Massachusetts is about $2 a month. There are many cases where the cost for a full year averages about $10 and even less for a mobile station used in daily police service, traveling about 4000 miles a month. The costs in no case average over $5 a month per mobile station as used in police service or the equivalent. Individual car costs fluctuate greatly because one might need a new microphone or a dynamotor while others might need not even a tube for an entire year. Transmitter tubes receive more abuse than receiver tubes and have less life in terms of actual hours of transmission or reception. Receiver tubes, although usually guaranteed for only 1000 to 2000 hours, can be depended on for an average of 5000 hours or more. The receiving efficiency may be low as compared with new tubes but still be adequate for satisfactory communication. Transmitter tubes have a life closer to the guaranty period, depending on how much the transmitter is permitted to load up. A 10-watt set operated at 5-watt output naturally has longer tube life than a 10-watt set operated at 12-watt output.

Theoretically, nothing but tubes should have to be replaced. In practice, tubes represent half the total maintenance cost. Breakdowns or replacements, such as a microphone, dynamotor, damaged meter, defective switch, represent the other half. Antennas and cables on cars may require replacement every one to two years, depending on reinstallation frequency, since many users of two-way facilities exchange cars usually once a year.

Another expense that may arise is a special heavy-duty charging generator and large-capacity storage battery for radio-equipped cars, but such expense is not always necessary.

6 Equipment Components

Equipment components differ between amplitude and frequency modulation. There is also a difference between microwave equipment and that suitable for lower frequencies.

The transmitter components comprise:

1. Radio frequency oscillator to generate the high-frequency alternating current required.
2. Buffer stages to act as intermediate power amplifier or as frequency multiplication device. Such stages are generally used in higher-powered or more elaborate equipment. In mobile stations they are usually omitted to conserve power consumption and space.
3. Final radio-frequency amplifier to build the frequency set up in the oscillator to a desired power level before it is allowed to propagate in space from the antenna system. This is the largest and most costly tube in the entire two-way radio station. The power supply for a station has to have a rating able to handle this tube. Since this tube handles the most power and at the highest frequency in the circuit, it may be expected to have less than the average life of other tubes. Obsolete equipments use a tube that may cost more than $100, while modern equipments have a more efficient tube, costing possibly one-tenth that figure. Some equipments have tubes in this stage that perform satisfactory mobile service at costs between $1 and $3.50, depending on the power employed.
4. Microphone with press-to-talk switch button.
5. Pre-amplifier, used only in high-powered stations.
6. Speech amplifier to amplify microphone pickup before permitting it to reach modulator.
7. Modulator driver or intermediate stages, used only in high-powered stations.
8. Modulator to impress sound on the radio carrier wave so that the latter can act as the vehicle for intelligence from transmitter to receiver points.
9. Power supplies, such as dynamotors, vibrators, rectifiers, to convert the primary power from 110 volts AC, storage battery, or other source, so that it will be of correct value and characteristic for the various circuit requirements.

The receiver components comprise:

1. Radio-frequency amplifiers to amplify the incoming signal to a satisfactory level before it is utilized.
2. Detector or demodulator to separate intelligence from the radio carrier wave. In the case of FM, it is called a discriminator, since it separates intelligence by responding to variations in frequency rather than amplitude.
3. Intermediate-frequency amplifiers (IF stages) to amplify the signal after initial detection and prior to final detection or demodulation. They are employed in the superheterodyne type of receiver where the incoming signal frequency is made to mix with a locally generated frequency. The difference of these two frequencies becomes the IF frequency. In the case of frequency modulation, one or more of these IF amplifiers are made to serve as limiter stages. This is done by using less plate voltage so that the tube will saturate at a lower level of power. Weak signals pass through normally. Loud signals cannot develop an amplitude beyond that permitted by the tube voltage.

4. Audio amplifiers to amplify the demodulated signal after final detection to any desired level for loudspeaker operation, limited only by the signal-to-noise ratio in the equipment.

5. Loudspeaker, headphone, or other reproducer to convert electrical variations into sound-pressure variations to which the human ear responds.

6. Power supply to light the tubes and energize the circuits.

The antenna system may comprise:

1. A vertical flexible or rigid metal conductor, such as the fishpole type on an automobile or other vehicle. Its length is generally equal to one-quarter of the wave length being used for communication. If not used with a ground, it usually is half a wave length long.

2. Tower, pole, or mast at a fixed station to act as a tall support, or, in the case of metallic structures, as the antenna radiator itself.

3. Antenna array on top of tower or mast at a fixed station.

4. A transmission line, either open-wire or enclosed coaxial type. Cozxial type is most common except on the very high microwave frequencies where wave guide may be employed.

5. Dry nitrogen or a dehydrator device such as a silica gel cell to keep the coaxial transmission line dry or free from condensation resulting from changes in temperature and weather.

Miscellaneous equipment required includes special housing or furniture to hold equipment and controls; equipment to check tubes, measure part values, analyze signal input and output; and circuit alignment facilities to measure frequency. New equipment is constantly being developed. Basic items to have are a tube checker, volt-ohm-milliammeter, signal generator, frequency meter, and simple tools, such as a soldering iron, pliers, wrenches, wire strippers. In the final analysis, men with the basic equipment listed accomplish more than impractical men who must have the most complete and elaborate test facilities for routine maintenance. Too elaborate facilities make the personnel physicists rather than maintenance technicians. Elaborate and complex equipment may get little use after its novelty wears off, since it requires too much preparation and takes too long to use on occasion. Systems should start out with only the basic items. Purchase additional items to suit the whim of the personnel or the need of the system after the system has functioned long enough to indicate justification for them.

All systems should carry a good supply of spare tubes. A satisfactory supply is usually 50 per cent of all the tubes in use by the entire system. It may be less if a procurement source is very convenient to the servicing depot; otherwise, carrying as high as 100 per cent spares may be justified. Critical tubes, based on experience and vibrators, may go over 100 per cent. A spare antenna should be carried for every three mobile units. For equipment using quartz crystals, there should be one complete set at

each servicing depot; more are permissible. Unless units can be permitted to stay off the air because of sufficient stations in the system, depots should carry a spare transmitter, receiver, microphone, and loudspeaker for purposes of exchange. If there are no spares, the equipment should be removed from the least important or inactive cars.

7 Purchasing Equipment

Equipment is ordinarily bought from manufacturers direct or via their distributors. Maintenance parts are ordinarily purchased from retail or wholesale dealers. Discounts up to 40 per cent off the list price are usually available to users of two-way radio equipment from any radio supply house or distributor. Consult the advertisements in various radio magazines, in case there is no local distributor. On some items, discounts up to 60 per cent off the list price are available if the manufacturer has no commitments to local dealers or distributors. On the other hand, some firms quote net prices and do not have a discount structure. The purchaser should determine the price-fixing basis employed by the firm patronized. In any case, a system involving several stations should not have to pay list price for equipment components. There should be a discount of not less than 20 per cent on high-cost items and about 40 per cent on low-cost items such as tubes. The consistency and amount of the purchasing justifies the granting of discounts.

The bid system is satisfactory only when supply exceeds demand. It should not be used when demand exceeds supply. At such a time, direct negotiation will effect great economies. For public agencies under the scrutiny of factional politics, it is advisable that the bid system be used even if it involves higher costs. Sometimes the bid system is first used to establish prices and equipment standards, and then direct negotiation with the bidders results in obtaining better equipment at even lower prices. In that way the requirements of a political agency are met, and a saving is also effected. Frequently these economies determine whether or not a system will materialize.

The following factors should be considered when selecting the equipment and the firm from which it will be purchased.

1. Cost of equipment.
2. Design and circuit specifications.
3. Whether the component parts have a sufficient factor of safety. There is no need of having an excessively large factor; 100 to 200 per cent is ample, and in some cases it can be less. A 500 per cent factor may mean large size, high price, and difficulty in replacement.
4. Ease of installation, dismantling, reinstallation.
5. Ease of servicing. Accessibility of all the parts determines this.

6. Ability of equipment to conform to the frequency tolerance variations permitted by the Federal Communications Commission.

7. Satisfied users of identical or similar equipment. If equipment is a recent development, as microwave facilities would be, some leeway can be allowed in this regard.

8. Simplicity or complexity of equipment. Some equipment is needlessly complex, merely to stand apart from competitive types or to justify a higher selling price.

9. Quality of component parts, particularly in regard to type of insulation.

10. Life and obsolescence of equipment.

11. Stability of equipment performance with regard to vibration, noise, humidity, and temperature variation.

12. Ease of tuning and adjustment.

13. Facilities included for observing equipment performance and modulation; whether incorporated or easy to insert.

14. Maintenance and replacement expense; ease of procuring replacement parts.

15. Whether equipment is custom built or produced in sufficient quantity to assure a moderate price.

16. Freedom from patent infringement or liability for patent fees resulting from construction, sale, or utilization of equipment. A patent can be in force in the United States for a maximum for seventeen years including renewal. It is common practice for a manufacturer to be licensed for a pool of patents. Such cross-licensing agreements make additional patent pools available to the same manufacturer. However, new developments may require additional licensing with groups outside these pools. Certain patents are public domain. The seller should guarantee to the purchaser in writing sufficient patent protection to make, use, and sell the equipment.

17. Guaranty and assurance that manufacturer or distributor will deliver equipment in amount, quality, and price stipulated.

18. Determination of equipment performance and power capabilities.

19. Ratio of primary power consumption to performance output.

20. Completeness of equipment and freedom from any hidden costs for accessories or services.

21. Agreement as to who pays shipping and packing charges.

22. Assurance that delivery dates will be as specified.

23. Understanding that parts which fail because of poor quality or inability to deliver the promised power or performance will be replaced without cost by the manufacturer for a specified period.

24. Whether any reduction in cost can be effected by purchaser co-operating with manufacturer or distributor:

- (a) If equipment is promptly accepted and paid for.
- (b) If purchaser picks up equipment at factory or from distributor without special crating or packing.
- (c) If sales expense is reduced or eliminated; no special trips or interviews.
- (d) If no commission or only a partial commission is paid by the manufacturer to make the sale.
- (e) If seller is relieved of field engineering services.
- (f) If seller need not provide planning, advisory, or other services at any time in connection with the sale.

All the above items are reflected in the sales price. This is particularly true for public agencies where one to two years of missionary and sales work are required to get an appropriation and approval for vital facilities. Frequently they resort to competitive bidding with all but one bidder destined to lose out, costing the bidders time and money which is reflected in the price each purchaser pays for the equipment. Cooperating purchasers should not be penalized for high sales costs for which others are responsible.

As protection to a purchaser using the bid system, the following clause can be inserted in the sales contract: "The purchaser reserves the right to reject any and all bids if specifications and prices are not acceptable or fall short of expectations. Purchaser also reserves the right to award to other than lowest bidder or to invite two or more bidders to co-operate jointly to meet communication requirements and to serve the best interests of the purchaser."

8 Licensing

The Federal Communications Commission in Washington, D.C., should be consulted for latest information on equipment and operator licensing. The requirements change from time to time to meet the rapid advancements in the radio art. In general, before a station can be constructed, an application is made to the FCC for a construction permit.

After this permit is granted, if a change in the construction dates or equipment is found necessary, application must be made for a modification of construction permit. Ordinarily when the construction permit is approved by the FCC, it is tantamount to a license, since call letters are immediately assigned.

When the construction is completed, application must be made for a radio station license. This is automatic and logical. The FCC requires the construction permit application as it must know that a new station is contemplated, to prevent disrupting existing services. Furthermore, when once approved, the FCC protects the new station from encroachment on its channel rights without authority. The radio station license verifies the completion of the new station; otherwise, there would be no way of knowing whether the licensee exercised his permit.

Operators are also licensed. Rules have been increasingly liberalized for two-way radio service as the service expanded. Persons who merely operate the equipment must have simple restricted radiotelephone operator permits, sometimes called third-class radiotelephone operator license. Maintenance personnel who handle equipment tuning that might cause inoperation have to prove their competence by holding a radiotelephone second-class license or higher. If the system is constantly

monitored or controlled by a full-time professional maintenance man holding a professional license, the individual operators can get authorization to be relieved of holding licenses themselves. However, the license examination is so simple that the system frequently finds it useful to require the license for purposes of radio discipline and control. The examination consists of only ten questions on regulations pertaining to profanity, superfluous conversation, deliberate interference, violating the security of radio transmissions, and the like. It impresses the personnel to maintain reasonable discipline on the air and not engage in horseplay. The FCC usually grants permission to conduct examinations locally by nominating some responsible person to handle the details.

CHAPTER THREE

POWER SUPPLY

1 Primary and Secondary Sources

In the case of mobile stations, the limiting factor in deciding how much power a station shall have is dependent on the type and quantity of electrical current available.

In very small self-contained portable sets, such as the handie-talkie or walkie-talkie types, where space and weight are important, very special power provisions are necessary. Small flashlight-type batteries are used to light the filaments, while the very smallest size cells are used in series combination for the B or plate battery. Such batteries have a very short life, and their life is not restorable. They are of a type and number to furnish the voltages required in a circuit without further conversion or provision. They are uneconomic except for very low-powered equipment in purely temporary or intermittent service.

Most two-way radio equipment is designed to function from a storage battery or from standard electric-lighting power mains. This power cannot be applied to all the circuits in the equipment because the voltage may be incorrect, or it may be AC where DC is required, or vice versa. It therefore requires one or more of the following components in any particular two-way radio station either to provide or to convert electrical current to energize the equipment.

1. Storage battery.
2. Generator or other type of device to charge the storage battery from an engine, wheel axle, lighting mains, hand power, or the wind.
3. Dynamotor or genemotor to convert 6-, 12-, or 32-volt storage battery direct current into voltages of 200 to 1000 volts DC, to provide the plate and other high potentials needed by the vacuum tube circuits for a mobile or a fixed emergency station.
4. A vibrator to convert direct current of low voltage from a storage battery into high voltage for the vacuum tubes. This is instead of a dynamotor.
5. Rotary converters which are actually motor generators that convert DC into AC, or vice versa. They are available in AC or DC, any voltage, any AC frequency, and phases with respect to either their input or output.

6. Rectifiers which use vacuum tubes or chemical discs to convert AC into DC.

7. Wind generators that function by wind power to charge a storage battery. This, in turn, is made to furnish uniform power despite variable charging rates.

2 Storage Battery

The lead storage battery is one of the most common sources of primary power for two-way radio equipment in a moving vehicle. A storage battery can supply a high current in amperes at a low voltage. The common voltages to be encountered are 6 volts in an automobile, 12 volts on a boat or plane, or 32 volts in a railway car.

Its great advantage is the fact that it can be recharged by a small generator driven off some moving part of a vehicle in motion. Regardless of the variations and interruptions in the charging rate, resulting from a vehicle changing in speed or being stopped at intervals, for practical purposes the storage battery can provide constant current and voltage for radio operation.

On occasion the storage battery can furnish current for several hours, if need be, while the vehicle is not in motion and unable to charge the battery. It can make up for this amount of battery discharge later when the vehicle has its engine running or is in motion itself. For brief transmitting periods it can also furnish much higher outputs than the maximum generator charging input to the battery. In effect, the storage battery is a reservoir of electrical current, accumulating a supply of electricity whenever opportunity affords, and making available the required current drain on occasion. When two-way radio equipment is operating off a 6-volt storage battery, a continuous load of about 8 amperes during reception and standby increasing to as much as 50 amperes during actual transmission on voice, is encountered. This the average automobile storage battery is able to provide. The charging generator should have a normal charging rate at the most common speeds of the vehicle, which will be sufficiently above the continuous rate of 8 amperes to make up for the intermittent transmitting load of 50 amperes, or whatever it may be for a specific installation.

3 Dry Battery

Like the storage battery, the dry battery also provides pure direct current. Its capacity is much less than that of a storage battery. Once exhausted it cannot be recharged; it must be discarded and replaced by a new and different battery. Because dry batteries are expendable and have a very low current capacity, it is uneconomic to use them for any but very special applications.

They are useful for very low-powered self-contained portable equipment requiring a small drain; for pure emergencies, or for ordinary use for intermittent periods of very short duration. In such cases the importance of the application and the lack of better or other power facilities justifies such expensive and unreplenishable power.

The entire current capacity of a dry battery cannot be utilized; the percentage depends on the discharge rate and the periods of discharge. The smaller the current drain and the more intermittent the usage, the longer the battery life will be. When batteries get too low, it is possible to obtain some of the remaining current capacity by connecting them in parallel combinations. Two weak batteries in parallel might serve as well as one stronger battery by itself.

Dry batteries are based on individual cells of approximately 1.5 volts each. To have more voltage, the required number of cells are connected in series. This adds their individual voltages but keeps the capacity in amperes for the combination equal to that of one cell. To have more current capacity to handle larger current loads, the cells are connected in parallel. This adds their individual capacities in ampere hours but keeps the voltage of the combination equal to that of one cell. Where dry batteries must be used to supply both high voltage and a relatively high amperage discharge rate, larger batteries are used in which the cells are connected in series-parallel combinations. The scheme being for the series-connected cells to develop the high voltage and the parallel connections of these series cells to develop the current drain required.

The standard flashlight battery cell has a capacity of about 5 ampere hours. It is used satisfactorily to operate the filament of 1-volt tubes drawing 60 milliamperes. When possible, two of these cells are connected in parallel to do that job. They are nearly equivalent to three cells used individually, because of the capacity of the two cells plus the extra drain that becomes available by having them in parallel, making it possible to draw half as much from each cell when in use. When the cells drop off, the output of two in parallel is still enough to be useful. A 45-volt B battery is usually considered unsatisfactory when it drops off to 35 volts, because it fails in service when operated under load.

Dry batteries deteriorate while in storage or on the dealer's shelf. They should be used within a year, the exact period varying with conditions. Dry batteries should never be left in an equipment indefinitely and forgotten. They eventually corrode, since they are chemical in composition and behavior and will damage metal or other material adjacent to them, or housing them, if retained too long. They should be checked every few weeks to prevent this condition, particularly toward the end of their useful life period.

Dry batteries can have their cells constructed in the same manner and of the same materials regardless of size and capacity. **Each cell still has the same voltage regardless of individual size. Larger dimensions mean larger current capacity in ampere hours.**

4 Dynamotor

To develop the high voltages required in a radio transmitter used in mobile work, with a current drain up to several hundred milliamperes, miniature motor generators have been developed for operation from a storage battery. Such a motor generator comprises a direct current motor with a common armature shaft to serve a small dynamo or direct current generator. The word "dynamotor" was coined to indicate a dynamo driven by a motor. It is also called a genemotor to indicate it is a generator driven by a motor.

Dynamotors are available in a wide choice of input and output voltage and current sizes. Popular inputs are 6, 12, or 32 volts DC from a storage battery. The relatively low voltage and high current is transformed into a relatively high voltage and low current. Such devices have a maximum efficiency of about 65 per cent in converting low voltage into high voltage. The difference is lost in the energy necessary to operate the motor, friction, heating, and other effects The maximum efficiency is not obtained until the load is equal to the output for which the machine is designed.

To keep the size and weight down, the dynamotor rotates at a very high speed, such as 4000 revolutions per minute. The higher the speed, the higher the voltage developed. If the battery is weak, the speed is reduced, and the output voltage and regulation is poor. If the load is too great, the voltage regulation is poor; that is, as the load increases, the output voltage goes down. In the case of amplitude modulation, such fluctuation shows during speech if the dynamotor has inadequate capacity or insufficient voltage input.

To use dynamotors at high rotating speeds, better ventilation is required to prevent overheating. Since they are usually found only in the transmitter component of two-way radio stations, they can be overloaded with safety for the brief periods of a transmission. This is not permissible for continuous or fairly continuous loads. For such uses, the dynamotor should be oversized and rotate at a slower speed, such as 1800 revolutions per minute. It should then also have better ventilation provisions. As used in two-way communication for transmission only, a dynamotor normally has a life of many years, requiring only an annual check for brush and brush-spring adjustment or replacement and possibly relubrication. Since the average station only transmits a few minutes per day,

frequent lubrication is not necessary. Some dynamotors are never lubricated again once they leave the factory.

For the equipment types described in this book, dynamotors range from 300 to 600 volts output and deliver from 150 to 400 milliamperes of current for transmitter operation.

The dynamotor is not used to furnish power to light the tube filaments. Usually that is handled directly from the storage battery by using 6.3-volt tubes with indirectly heated cathodes.

5 Vibrator Power Supplies

A vibrator is a mechanical device used to convert direct current into pulsating or interrupted direct current or alternating current. The common types of vibrators utilize a vibrating armature and one or more sets of electrical contacts.

As radio came into wide use in cars, trucks, busses, boats, airplanes, it became necessary to develop some means of converting low-voltage direct current into voltages and currents usable in radio receivers. It was necessary to convert the 6-volt DC supply of the common car and airplane batteries into from 100 to 300 volts DC. These high voltages are used in the plate supply of radio equipment. To serve this purpose the mechanical device known as the vibrator was developed.

Vibrators are classified as:

1. Nonsynchronous: half-wave series, full-wave series, full-wave shunt. These types require rectifier tubes.
2. Synchronous: half-wave series, full-wave shunt. These types are self-rectifying.

The construction of a vibrator includes:

Armature. A small spring steel reed fastened securely at one end and free to vibrate at the other end. The width, length, weight, elasticity, and tension of this steel reed must meet exact specifications. The reed material must have a very high tensile strength. The secured end of the reed is called its pivot point.

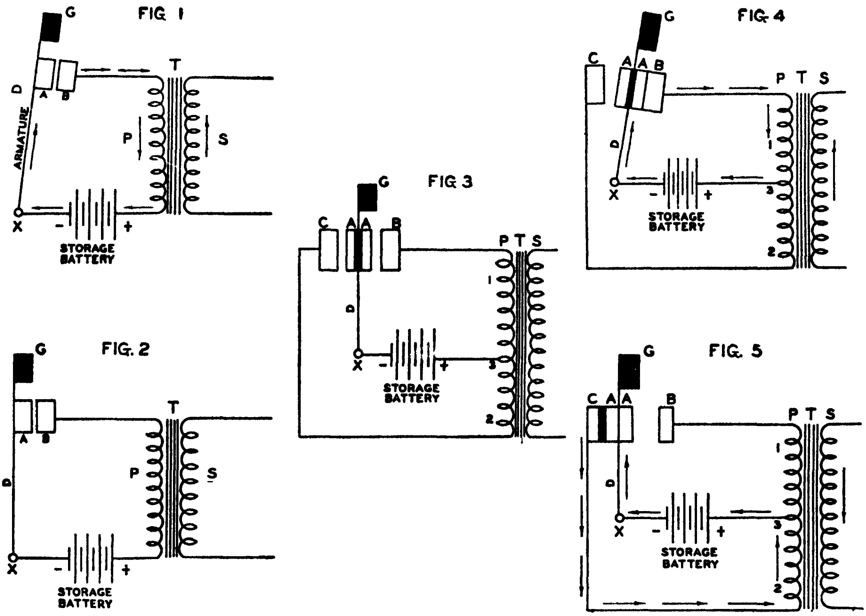
Armature Contacts. Used to make and break electric currents when the reed vibrates. They are made of tungsten, phospher bronze, or some other hard metal, and must be able to break current without pitting or corroding. A fixed contact is one which is held securely and moves only when contact is made with the armature. The vibrating contact is attached to the reed, and moves back and forth, making and breaking the electrical circuit.

Counterweight. A relatively heavy weight secured to the vibrating end of the armature. It is used to increase the inertia of the reed. The weight of the counterweight must be held to close specifications.

Actuating Magnet. Consists of a coil of wire and a soft iron core. It is used to attract and release the armature, and keeps the reed in motion. The inductance of the magnet coil is very critical. The magnet must provide just the right amount of attraction to the armature.

Terminals. Convenient terminating points for the electrical circuits of the vibrator, provide a means of connecting the vibrator into the circuit. The terminals are usually of the type used on radio receiving-tube bases, and usually fit into standard tube sockets.

Soundproofing. The mechanical vibration of the vibrator makes considerable noise which is confined within the vibrator by means of sponge rubber or some other poor conductor of sound. Sometimes two or more insulation covers are used. Each insulation material is placed in a separate cover.



Vibrator action.
Figs. 1 and 2, nonsynchronous half wave.
Fig. 3.
Fig. 4.
Fig. 5.

Shielding. The vibrator must be completely shielded to prevent the radiation of electrical disturbances. The shielding material may be aluminum or some other good conductor of electricity. The vibrator shield must be well grounded to the chassis of the receiver.

Simple vibrator action of the nonsynchronous half-wave series type is illustrated in the accompanying diagram. The parts used in the first two figures are:

Armature or vibrating reed (D).
Storage battery.
Transformer primary (P).
Transformer secondary (S).

Armature counterweight (G).
Contacts (A and B).
Pivot point (X).

The arrows indicate the direction of the current flow. The action is as follows:

1. Contact being made between A and B.
2. Current flows from battery through armature, through contacts, through primary of transformer, and back to the battery.
3. The building up of the current in the primary induces a current in the other direction in the secondary.
4. The contacts A and B remain closed only for a brief interval.
5. When the contacts A and B are separated, current no longer flows in the circuit.
6. The decrease in the current in the primary induces a current in the secondary in the opposite direction.
7. The action is now repeated.
8. The complete action described above provides an alternating current in the secondary of the transformer.
9. This alternating current is rectified and converted into DC either by a mechanical or an electronic device.
10. The increase in voltage is obtained by the step-up ratio of the transformer.

A disadvantage of this type of vibrator is that the contact points have a tendency to stick together. This shorts the storage battery through the transformer. The short circuit causes the set wiring or vibrator, or both, to burn up.

The action of the nonsynchronous full-wave vibrator is illustrated in the third part of the diagram. The parts used are:

Armature or vibrating reed (D).
Storage battery.
Transformer primary (center tapped) (F).
Transformer secondary (S).
Armature counterweight (G).
Contacts (A, B, C).
Pivot point (X).

Arrows indicate the direction of current flow, and the action is as follows:

1. When the armature is in the center position no current flows in the circuit.
2. When the armature is in the position shown in the fourth figure, contact is made between A and B.
3. The current flows from the battery through the armature and the contact points.
4. The current then flows through the top half of the primary and back to the battery.
5. This flow of current induces a current in the secondary.

6. The armature then swings back and makes contact at A.C.
7. The current then flows through the bottom half of the primary in the opposite direction.
8. This flow of current in the bottom half of the primary induces a current in the secondary in the opposite direction.
9. The action is then repeated.
10. This action is called full wave and produces a truer form of alternating current.
11. This alternating current is rectified and converted into DC by a mechanical or an electronic device.
12. The increase in voltage is obtained by the step-up ratio of the transformer.

In addition to the vibrators described here, the Electronic Laboratories of Indianapolis, Indiana, have had considerable success in developing vibrators to handle exceptional amounts of power, exceeding that of the average dynamotor used in communication.

These vibrator interrupters convert direct current into alternating current; direct current into different voltages of direct current; and alternating current into different frequencies and voltages of alternating current. By means of parallel operation, methods have been devised to deliver as much as 1000 watts of power that way.

These high-power vibrators are available in three basic types as follows:

1. The converter type with standard input voltages of 4, 6, 12, 24, 32, 64, 110, and 220 volts. Standard frequencies are 60, 100, and 120 cycles.
2. The tandem type which has a greater input wattage rating through the use of multiple contact points, making possible an input wattage rating as high as 1000 watts in special inverter circuits. Also by synchronizing one or more vibrators of the tandem type, combined wattage ratings as high as 1000 watts input can be obtained in converter circuits.
3. The polarity changer type used to produce DC to AC in which no transformer is involved. One common use is to change 110 volts DC to 110 volts 60-cycle AC. Maximum output wattage rating for the standard size is 150 watts, for the tandem size 300 watts. Average life expectancy of the replaceable vibrator unit is 1500 hours.

6 Rotary Converter

When electric power is already available but is of the wrong kind, a larger type of dynamotor is used, called a rotary converter. This too is a motor and a generator on a common shaft. Rotary converters are widely used for transformation or rectification where the regular power is DC, and AC is required; also where the available power is AC, and DC is required to operate certain components. They are also useful where the line voltage is a higher or lower DC or AC than is required.

Rotary converters are available in a wide selection of inputs and outputs, either AC or DC. They are also available with more than one

INPUT AND OUTPUT DATA FOR ROTARY CONVERTERS MANUFACTURED BY PIONEER GENERATOR CO.

Armature Speed 1800 Rpm.

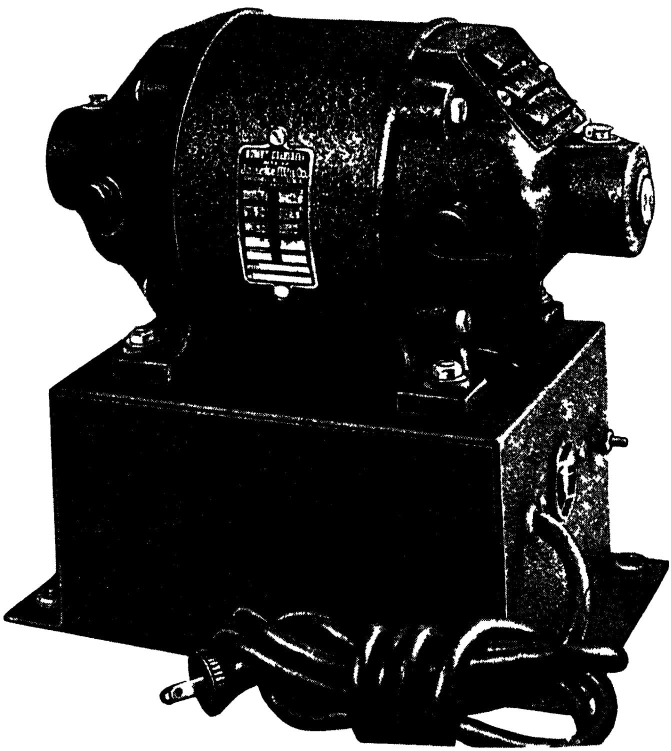
DC Input Volts	DC Input Amperes	AC Output Volts	AC Output V.A. at 60 Cycles	AC Output V.A. at 50 Cycles
12	42	110	300	250
32	14.5	110	300	250
32	18.5	110	400	325
32	22	110	500	400
32	33	110	750	600
32	44	110	1000	800
115	4.2	110	300	250
115	5.4	110	400	325
115	6.4	110	500	400
115	9.4	110	750	600
115	12.4	110	1000	800
230	2.1	110	300	250
230	2.7	110	400	325
230	3.2	110	500	400
230	4.7	110	750	600
230	6.2	110	1000	800
32	54	110	1250	1000
32	65	110	1500	1200
115	15	110	1250	1000
115	18	110	1500	1200
115	23.6	110	2000	1600
115	28	110	2500	2000
115	33	110	3000	2500
230	7.5	110	1250	1000
230	9	110	1500	1200
230	11.8	110	2000	1600
230	14	110	2500	2000
230	16.5	110	3000	2500

Armature Speed 3600 Rpm.

DC Input Volts	DC Input Amperes	Output at 90 Per Cent PF AC Volts	V.A. at 60 Cycles	V.A. at 50 Cycles
6	14	110	40	30
6	20	110	60	50
6	36	110	110	90
12	8.0	110	40	30
12	13.5	110	80	60
12	17.5	110	110	90
12	24	110	160	125
12	42	110	300	250
24	4.0	110	40	30
24	6.8	110	80	60
24	8.8	110	110	90
24	13.9	110	200	160
24	19.4	110	300	250
24	30.4	110	500	400
32	2.8	110	40	30
32	4.8	110	80	60
32	6.2	110	110	90
32	10.4	110	200	160
32	14.5	110	300	250
32	22.0	110	500	400
32	34	110	750	600
48	2.0	110	40	30
48	3.4	110	80	60
48	4.4	110	110	90
48	7.0	110	200	160
48	9.7	110	300	250
48	15.2	110	500	400
48	22.7	110	750	600
115	.8	110	40	30
115	1.4	110	80	60
115	1.8	110	110	90
115	3.0	110	200	160
115	4.2	110	300	250
115	6.6	110	500	400
115	9.4	110	750	600
115	12.4	110	1000	800
230	.4	110	40	30
230	.7	110	80	60
230	.9	110	110	90
230	1.5	110	200	160
230	2.1	110	300	250
230	3.3	110	500	400
230	4.7	110	750	600
230	6.2	110	1000	800

winding, in the event more than one kind of current output is required. They are widely used to operate 110-volt 60-cycle alternating current equipment on ships or trains, or in DC areas at fixed points. A typical example is a locomotive having only 64 volts DC available, but requiring 110 volts 60-cycle single-phase AC to operate radio equipment.

To reduce interference caused by brush sparking and commutator ripple, a filter system is usually incorporated in the same mounting with



A modern type of rotary converter or dynamotor. (Courtesy Janette Manufacturing Co)

the converter. Such interference is more pronounced on amplitude modulation receivers than on FM receivers. It is also common to the dynamotor, which has similar provisions, but it is not serious there, since less power is involved.

7 Rectifiers

In radio equipment, fairly high voltages are encountered. A 25-watt equipment may have a voltage as high as 400 volts; 50-watt equipment may use a voltage as high as 600 volts; 100 watts may go to 2000; and

1000 watts may use about 4400 volts maximum. It is also possible to develop high power by using smaller tubes in parallel, thereby using lower circuit voltages but a correspondingly higher circuit current in milliamperes to make up for it.

While selenium or chemical rectifiers can be useful in radio communication equipment, present-day equipment relies on the vacuum tube rectifier usually contained within the transmitter and receiver components. The vacuum tube rectifier is a very valuable device to convert high-voltage alternating current into high-voltage direct current. It does this with a high degree of efficiency that exceeds the mechanical dynamotor or converter. Furthermore, it involves no moving parts and is silent as well as vibrationless for all practical purposes.

The purpose of the rectifier is to produce unidirectional or essentially DC current from an alternating current. By using vacuum tube rectifiers, this voltage can be handled after it passes through a step-up transformer. For example, a 110-volt 60-cycle AC current is fed into the radio power transformer and is stepped up to 2000 volts. The 2000 volts rather than the 110 volts is applied to the rectifier tube so that 2000 volts minus a few per cent transformation loss is available in direct current unidirectional form. When it passes out of the tube, it is still not pure direct current as compared to that available from a battery. It is necessary to further smooth it out and filter it through a filter network made up of capacitance and inductance. Upon passing through the filter system it is direct current pure enough for the utilization involved.

The following description covers the types of rectifiers usually encountered in two-way communication equipment where AC is the power source.

Rectifier Action of a Vacuum Tube. A two-element tube will pass current in one direction, and will only pass current when the plate of the tube is at a positive potential with respect to the filament. The amount of current a tube will conduct is dependent on the construction of the tube; the value of the load resistance; and the amplitude of the voltage applied to the plate of the tube.

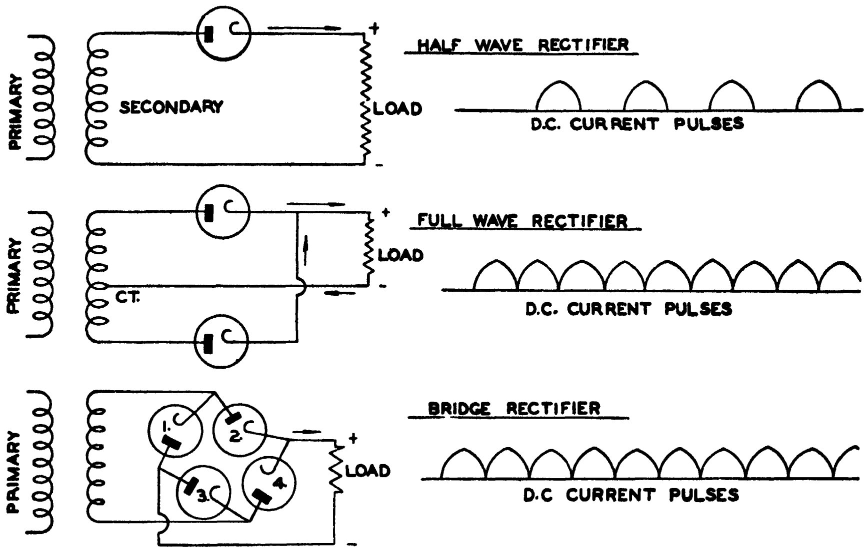
Half-Wave Rectifier. When current flows only during half of the cycle, the rectifier is called a half-wave rectifier.

1. Referring to the circuit shown in Figure 1, the plate of a two-element tube is connected to one side of a secondary winding on a transformer. The other side of the winding is connected through a load resistor to the filament of the two-element tube.
2. When an alternating voltage is applied to the primary of the transformer, there is an alternating voltage set up in the secondary.
3. This alternating voltage as seen in Figure 1, is applied between the plate of the tube and the filament.

4. When the plate end of the winding is positive with respect to the filament end, the tube will allow a current to flow through the resistor. When the plate becomes negative, the current will no longer flow.

5. As the potential applied between filament and plate is alternating, current will only flow in the load resistor during the half cycle when the plate is positive.

6. There is, therefore, a pulsating direct current flowing in the load resistor.



Types of tube rectifiers.

Full-Wave Rectifier. Where both halves of the cycle are utilized, the action is called full-wave rectification.

1. To utilize both halves of the alternating voltage, it is necessary to connect two half-wave rectifiers as shown in Figure 2.

2. In this circuit one of the tubes conducts during the positive half of the cycle, and the other tube conducts during the negative half of the cycle.

3. As shown in Figure 2, both filaments are connected to one side of the load resistor, and the other side of the resistor is connected to the center tap of the secondary winding of the transformer.

4. When the upper end of the winding is positive with respect to the center tap, tube No. 1 conducts, and a current flows through the load resistor.

5. When the lower end of the winding is positive with respect to the center tap, tube No. 2 conducts, and a current flows through the load resistor in the same direction.

6. There is, therefore, a pulse of current through the load resistor for each half cycle of the alternating voltage appearing across the secondary of the transformer.

Bridge Rectifier. To obtain the full voltage of a transformer (that is, between the two outside terminals), it is necessary to use a bridge rectifier. This is shown in Figure 3.

1. A bridge rectifier may be used on a transformer without a center-tapped secondary.

2. Referring to Figure 3, when the upper end of the transformer winding is positive with respect to the lower end, current will flow through tube No. 2 and throughout the load resistor to tube No. 3 which will also conduct, allowing the current to flow and complete the circuit back to the lower end of the winding.

3. When the lower end of the winding is positive, the current will flow through tube No. 4 and tube No. 1, and back to the top of the winding, thus completing the circuit.

4. In this manner, both halves of the cycle are utilized, and the full voltage of the transformer is utilized. This is also full-wave rectification.

5. If the conventional full-wave rectifier circuit had been used, only half of the voltage would have been obtainable, due to the necessity of tapping the winding at its midpoint to provide a common return.

6. This circuit uses twice as many rectifier units as the conventional full-wave circuit.

7. The allowable current available from this rectifier circuit is only half that which would be obtainable from a midtapped transformer full-wave rectifier circuit.

8. It is necessary to use filters to smooth out the pulses of direct current in all of the above rectifier circuits.

8 Independent Power Plants

When 110-volt AC is required to operate standard radio equipment as well as lighting and other electrical fixtures, it is feasible to provide an independent power plant for that purpose. This is also advisable for emergency power in the event the power lines fail. It is possible to generate current at a cost as cheap but no cheaper than the average rate charged by power companies in small quantities; for example, five cents per kilowatt hour. That figure is based on fuel and lubricating oil only.

The usual power plant is a gasoline engine driving an AC generator. Quite often, this generator has more than one winding. For example, it may be designed to deliver 110 volts AC and also 6 or 12 volts DC, to charge a storage battery simultaneously. This storage battery makes possible automatic starting from a remote position. It is also possible by the use of incorporated relays to have equipment which stops when there is no load and starts up immediately when a circuit somewhere is closed and draws electrical current.

In selecting an AC power plant, the mistake is often made of not carefully considering the power factor caused by the nature of the load. If the load is inductive, that is, if it is feeding into wire in coiled form, such as a transformer, then the current going through the coil has a tendency to reach a maximum value at a time different from the maximum voltage in that circuit. A watt is the unit of electrical power. Wattage equals volts multiplied by amperes at any instant. If the voltage is 100 volts and the

current is 10 amperes at a certain instant in a circuit where the current and voltage are in step, there is 1000 watts of power. But if the voltage is 100 volts and the current is 8 amperes at a certain instant, because the load is inductive and causes the current to lag the voltage, then only 800 watts can be obtained from a 1000-watt generator based on 100 per cent unity power factor.

If the load is capacitive rather than inductive, the current leads the voltage, and the opposite takes place. There might be a maximum current of 10 amperes, but at that moment the voltage might be only 75, giving a total effective wattage of 750 watts from a 1000-watt 100 per cent power factor machine. It is then said that there is a power factor of 75 per cent.

Therefore, in selecting a power plant, it is not sufficient to know the wattage output rating of the machine; it is also necessary to know the power factor for that amount of power. No 100 per cent power factor is attained in practice, although it is possible if a means is provided to balance inductive loads with capacitive loads, or vice versa. Pure resistive loads, such as lighting bulbs, do not have much effect on the power factor. It is usually the inductive load at the consumer's point plus the capacitive effect of the wire spacing from power plant to consumer, and these can be balanced by artificial means.

No power plant is recommended for two-way communication stations unless it can as a minimum handle the maximum load at 80 per cent power factor. In other words, if the radio equipment requires 500 watts 110 volts AC 60-cycle single-phase, the power plant should at 80 per cent of its wattage rating be able to deliver 500 watts. Usually a power plant should be twice the size for the load to take care of extra lights and to improve the voltage regulation as the load fluctuates. If the load is an important part of the generator output, the voltage of the machine is hard to regulate at a stable value, since it falls off suddenly when the load is applied.

Too small a gas-driven power plant may actually stall the engine if it is overloaded, as well as cause the generator to overheat and misbehave. This is not too marked with a steady and stable load. It is, however, quite important to allow for this if the load is intermittent or variable, such as from no load to full load when a microphone button is depressed during transmission. During emergencies, when a power plant may be overloaded because it may have to provide lighting as well as power for radio equipment, transmitter operation is improved by cutting out the lights and the radio receiver during actual transmission. This involves a small delay for the receiver tubes to warm up again but it saves the power plant from trying to carry too much of a load. It also safeguards the receiver

from a sudden power surge when the transmitter load is removed. Such considerations do not arise if the power plant is of adequate size for the load and the power factor involved.

The amount of power of a gasoline engine varies with the elevation above sea level. For example, at 15,000 feet it may have only 50 per cent of its horsepower; at 2000 feet it has about 90 per cent. This should be remembered in order to select a power plant of the correct size.

Power plant exhausts should be piped outside to protect human life. Also, fresh air should be available from outside to make up for the oxygen consumed by the gasoline engine inside the building.

Automatic plants can be started by the storage battery feeding back into the generator to make it act as an electric motor long enough to start up the gas engine. Manual plants use either a crank handle or a crank rope on the pulley provided for that purpose.

Power plants are available for private use from the lowest power to as high as 25 kilowatts or more. Usual two-way radio station plants are between 300 and 1500 watts, depending on what equipment is available for emergency use. Some radio stations prefer to have small mobile sets to energize during emergency rather than to have power plants large enough for the main transmitter.

9 Wind Generators to Charge Storage Batteries

Wind-driven generators are available in regular production models in 6-volt, 12-volt, and 32-volt sizes to charge storage batteries. They operate automatically and without fuel cost whenever there is any wind. The amount of wind necessary depends on the size of the propeller. A wind between 6 and 8 miles an hour will operate the generator and commence battery charging. Wind speeds greater than 20 miles per hour are not desirable. When that velocity occurs, an air-brake governor, consisting of flaps operated by the force developed at such high rotating speed, diverts the wind from the propellers.

Of course, such generators cannot generate power when there is a calm or wind less than the minimum velocity, but there are very few places in the world where suitable wind speeds are not available at least a few hours a day. In midwest sections of the United States, the limited number of windbreaks, the flat terrain, and the presence of wind of a consistent and adequate amount makes wind generators very useful for rural and remote locations having no other available electricity.

This type of generator is comparable to an automobile charging generator and car battery. Instead of the generator running off the automobile engine, it operates by the wind striking the propeller blades. This is a patented device manufactured by the Wincharger Corporation of

Sioux City, Iowa, under U.S. Letters Patent No. 1,802,094, a copy of which is obtainable from the U.S. Patent Office for ten cents.

The low cost of this equipment, particularly in the 6-volt model, is the result of its wide utilization among farmers to operate home radios. The radio industry has co-operated to keep these generators inexpensive, so that homes not equipped with electricity may enjoy the advantages of radio reception. Mass production methods have therefore been possible.

Radio interference is eliminated or is made unobjectionable by a generator condenser and grounding contact provisions. An instrument panel indicates whether the battery is charging and how much, and whether the battery is discharging into a load and the number of amperes. The panel also indicates the net amount of charge or discharge which exists at any moment when the battery is discharging into a load and at the same time is also being charged by the wind generator.

As in the case of the automobile, the equipment being operated receives its current from the storage battery where the supply is adequate, consistent, and fairly uniform. The load is therefore independent of wind conditions for any temporary period. The wind generator charges the storage battery whenever there is sufficient wind to turn the propeller at the required speed.

Such installations are useful on forestry towers and remote railroad relay stations, and can conceivably be adapted for a moving vehicle and for emergency uses where no fuel is available. In addition to operating radio equipment, they can provide minimum lighting and power for other electrical uses consistent with their capacity.

On special order, it may be possible to design and provide much larger installations. In some areas where there is limited wind or bad windbreaks, it may be desirable to elevate the generator on a tower or other vantage point.

10 Power Requirements for Typical Two-way Radio Equipment

The very small portable or walkie-talkie equipment may be entirely dry battery operated, particularly if it functions as a transceiver. The dry batteries can be as small as a tiny single flashlight cell to light the filaments and a miniature B battery to provide the plate voltage. The typical equipment described in this book uses the following input power:

5 watts FM. Comprising 4-tube transmitter using either 90 watts 110 volts AC or 11 amperes at 6 volts DC from storage battery; 11-tube receiver drawing 6.5 amperes at 6 volts DC.

15 watts FM. Comprising 6-tube transmitter and 12-tube receiver. To keep transmitter tubes warmed up during standby condition: 12 volts at 2 amperes.

To operate the receiver only: 12 volts at 4 amperes. Maximum load during transmission on voice: 12 volts at 12 amperes.

25 watts FM. Comprising 7-tube transmitter and 11-tube receiver. Standby load to keep transmitter tubes warm and ready to go: 6 volts at 2¼ amperes; total 13½ watts. Receiver during operation: 6 volts at 6½ amperes; total 39 watts. Transmissions (when loaded to 25 watts): 6 volts at 23 amperes; total 138 watts. Transmissions (when adjusted for 35 watts with same transmitter): 6 volts at 30 amperes; total 180 watts.

60 watts FM. Similar to 25 or 35 watts FM except that larger dynamotor is employed and two final amplifier tubes in parallel are used instead of one. To receive and to have transmitter in standby condition (tubes warmed up ready to depress button on microphone at any time) requires 9 amperes at 6 volts; total 54 watts. During transmission on voice, the load is 47 amperes at 6 volts; total 282 watts.

250 watts FM. Comprising 12-tube receiver and 15-tube transmitter. For receiver and standby condition draws 225 watts 110 volts AC. During transmission on voice, the maximum load is 1100 watts.

10 watts AM. Draws 6 to 8 amperes during reception and standby on 6 volts; total 36 to 48 watts. To transmit, it requires about 22 amperes at 6 volts; total 132 watts.

100 watts AM. The 14-tube transmitter draws 800 watts fully modulated by voice. It requires 150 watts during standby. Receiver draws 50 to 85 watts depending on type.

1000 watts AM. Maximum load is about 7000 watts during transmission on voice. About 400 watts during standby condition.

Because AM equipment requires an additional set of tubes and circuits almost equal to the radio transmitter proper in order to modulate the radio-frequency carrier wave, the load is almost twice as much watt for watt of output power. In the above cases, it takes from 4 to 7 watts input for each watt of transmitter output when using FM; the higher figure being at low power. It takes 7 to 13 watts input for each watt of transmitter output when AM, or amplitude modulation, is used. The elimination of an elaborate modulation system for FM gives it a tremendous advantage over AM in a mobile station where power source is limited. Watt-for-watt drain, FM will deliver twice the number of watts output. Frequency modulation has other equally important advantages.

Regardless of equipment type, there are certain minimum loads which cannot be proportionately reduced when comparing low-powered with high-powered equipment. For example, the receiver is almost identical in design and load requirements for small equipment as for large equipment. Also, certain relays to control the microphone circuit and transfer the antenna are identical. The number of intermediate circuits in an equipment also determines the ratio of input to output power.

The output wattage leaving the antenna is approximately 70 per cent of the product of the voltage times the current in the plate circuit of the final amplifier tube or tubes. For example, if a 50-watt FM transmitter

draws 150 milliamperes final plate current at 500 volts, this will be 75 watts input. The output should be about 70 per cent of that, or $.7 \times 75 = 52\frac{1}{2}$ watts. By adjusting the final plate tuning condenser or the antenna tuning circuit it can be loaded higher than that until the tube plates become red, or it can be reduced to a much lower level for cooler and better operation. Frequently, a system is overpowered for the utilization required. It is then desirable to reduce the final load to prolong tube life and reduce power consumption.

There are many stations, particularly in municipal service, that probably can cover their area with 5 watts instead of the 50 watts they may be using. They may not have known that such small power would be required, which explains why their tubes seem to last for years Actually, the tubes may have become inefficient and be delivering only a fraction of their normal power.

CHAPTER FOUR

THE MOBILE STATION

1 Mobile Radio Equipment

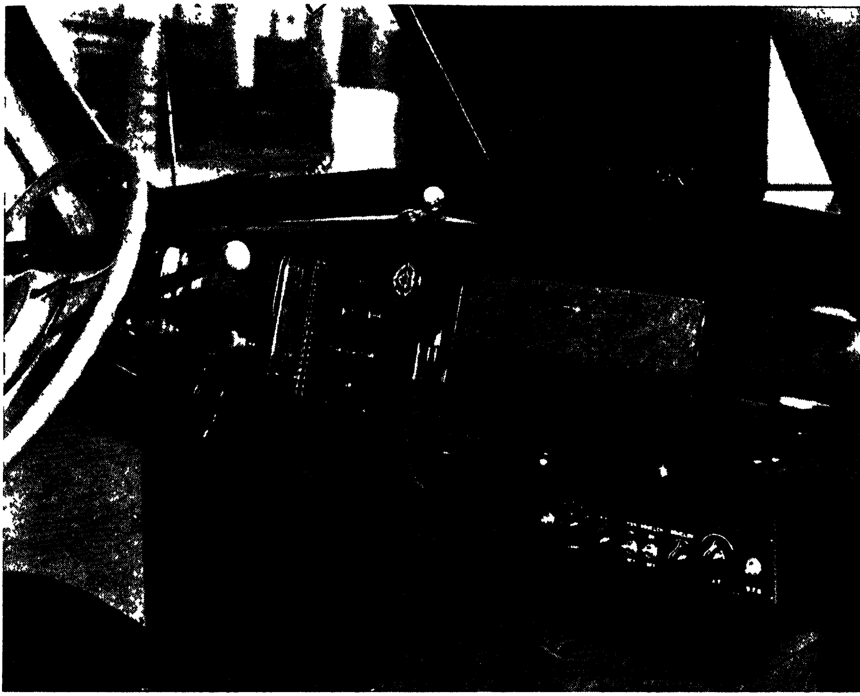
Mobile radio equipment as used for two-way radio communication is identical to low-powered fixed station equipment with certain exceptions. It is limited in power to the available source, which usually is a storage battery of low voltage such as 6, 12, or 32 volts DC. In the case of personalized types, such as the walkie-talkie, this is usually a dry battery to conserve weight and space as well as eliminate the possibility of acid spillage and corrosion.

Mobile radio equipment usually does not have rectifier tubes or power transformers. Instead, it depends on a dynamotor or a vibrator to develop the high voltages required. Many equipments use a dynamotor for heavy intermittent high-voltage load in the transmitter unit and a vibrator for the light continuous load that exists in the receiver unit.

Wherever possible, the equipment is kept compact to conserve space, which is usually at a premium in a mobile station. It is usually designed to have less weight than a fixed station of equivalent power. This is particularly true for aircraft, where not only must weight be conserved but also the parts must have a greater margin between operating voltages and breakdown or flashover voltages to take care of the tendency to flashover aloft under reduced air pressure.

The antenna of mobile radio equipment is of simple design, such as the vertical fishpole type, with a very short transmission line. While the antenna location and dimension may not be ideal as compared with a fixed station antenna, it is in part compensated for by the short transmission-line run from the equipment to the antenna. Thus, there is negligible transmission-line power loss in a mobile station; whereas in a fixed station the run may be so great as to consume an important part of the total transmitter power.

Usually the bulk of the equipment is located out of sight, such as in the rear trunk of an automobile, with only a small control box, micro-



The controls of Temco 25K long-range, high-frequency two-way mobile equipment shown in drivers compartment. Used for United States Border Patrol and Mexican War Department. (Courtesy Transmitter Equipment Manufacturing Co.)

phone, and loudspeaker visible and convenient to the operator. Frequently, the loudspeaker is concealed but is convenient to the operator.

Mobile station equipment has elaborate provisions and safeguards against vibration and shock. It has good shielding provisions as well as a good filter system to minimize interference and noise from the ignition system and moving parts of a vehicle.

2 Components of a Mobile Station

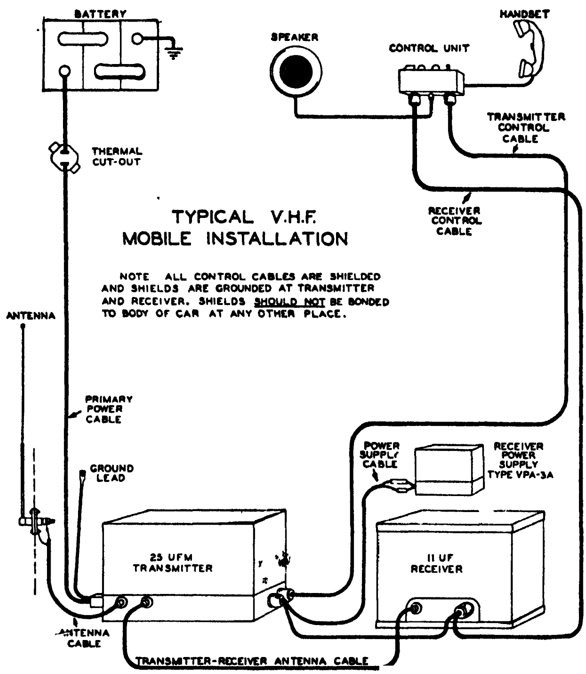
The components of a complete mobile station are:

1. A transmitter unit which during equipment operation is ordinarily in a standby condition with the tubes lighted and ready to be energized without delay. It may be located in the rear trunk of an automobile or in any available location in a train, boat, or plane. In the standby condition, it draws only about one-tenth the current it would draw during actual transmission of voice through space. Keeping the tubes warmed up stabilizes the transmitter frequency and prevents equipment from fluctuating in frequency while coming up to a stable temperature, particularly during cold weather.
2. A receiver unit which normally is in continuous operation with or without

provisions to cut off its high-voltage supply during the brief periods of transmission. This is mounted alongside or atop the transmitter unit.

3. An antenna mounted as close as possible to the transmitter and receiver units to minimize transmission-line losses.

4. A control unit which is usually mounted on the lower lip of the instrument panel in the driver's compartment of an automobile, or in some very accessible and convenient position in other vehicles. It is so located that the operator can reach it without leaving his normal working position. In a mobile unit, it is kept convenient to the front-seat passenger as well as to the driver.



Typical V.H.F. mobile installation. (Courtesy F. M. Link.)

5. A microphone mounted close to the control unit. A suitable bracket is provided for holding the microphone when not in use, so that it will not get damaged or fouled with other items.

6. A loudspeaker which is usually concealed but is in close proximity at an angle that aims the cone in the direction of the listener. Common locations are underneath the instrument panel grill, on the overhead, or underneath the dash in the case of an automobile. If located under the dash, reception is less ideal during the summer months when the cowl ventilator is opened, as the windstream diverts the sound.

7. Connecting cables:

(a) From transmitter to antenna.
(b) From receiver to transmitter to borrow same antenna.
(c) From receiver to transmitter to borrow the battery.

(d) Heavy cable from transmitter to storage battery for power.
(e) From receiver and transmitter in rear trunk to the control unit in driver's compartment to perform the following functions:

(1) To turn the receiver on and off.
(2) To light the transmitter tubes.
(3) To apply high voltage to the transmitter when the microphone button is depressed during transmission.
(4) To operate the antenna relay for switching antenna from receiver to transmitter during transmission, and vice versa during reception.
(5) To operate the loudspeaker during reception and make it insensitive during transmission.
(6) To control the volume of the received signal.
(7) To squelch out the interference and thereby have quiet reception, or to cut out the squelch when the extreme range is desired where provided.
(8) To operate a signal tone when provided.

The above-mentioned components are standard for most stations. They can be housed within one case, if desired, and can then be directly controlled and save many external interconnections. Inside, however, the equivalent of all the items listed above is required. An exception is the transceiver type of equipment operating on low power. The transceiver of the low power involved utilizes all or part of the components to perform dual duty, that is, serve both for the transmitter and for the receiver. When the change-over switch is in the transmit position, all the parts connect in a transmitting form of circuit. Upon completion of the transmission, the change-over switch is transferred to the receiving position, where the same parts are reconnected in a receiving form of circuit. This reduces the size, cost, and power consumption, which makes it useful for small personalized applications. Transceivers are only feasible for simplex operation; that is, situations where it is not necessary to transmit and receive simultaneously.

3 Causes of Shock and Vibration

The mobile station is designed to function at speeds that may be hundreds of miles per hour, as in the case of aircraft. It operates within reasonably narrow limits under a variety of conditions which tend to give it much abuse in the form of vibration and shock as well as erratic operating voltages within reasonably narrow limits.

It is important to understand the causes of vibration and shock in order to cope with them; otherwise, equipment damage and inoperation is inevitable. In the case of mobile radio equipment, vibration and shock may be produced by any or all of the following:

1. High speed of travel of the vehicle and its effect on the center of gravity.
2. Powerful high-speed engine plant.

3. Acceleration and deceleration of a vehicle.
4. Sudden starting and stopping of a vehicle.
5. Weaving rapidly in traffic and hard steering.
6. Firing armament or being the recipient of gunfire, explosions, and near misses.
7. Collision.
8. Top-heavy equipment and poor weight distribution.
9. Natural period of vibration developed by the size and weight of the component materials influenced by motion under conditions listed herein.
10. Irregular or washboard surface of the highway.
11. Two wheels on the highway and two wheels riding the shoulder.
12. Riding or crossing deep highway ruts.
13. Cross-country traveling over the ground.
14. Rough railroad roadbed, loose ties, or breaks between rails.
15. Cobblestones.
16. Leaping when encountering an obstruction, such as a rock on the road, or when encountering a frost heave in the road, as may occur after the winter thaws in the northern states.
17. Landing shock and air pockets in the case of a plane.
18. Passing over the seams between sections of concrete.
19. Abrupt hill and valley road surfaces.

4 Isolation and Absorption of Shock and Vibration

When a car on the highway strikes a frost heave at a high rate of speed, it leaps into space and receives a very violent thrust. In an actual case, such a thrust ripped the sheet-metal floor, on which the radio equipment was attached, out of the rear trunk. Thereafter, it was necessary for cars of that type to have a solid steel plate under the sheet-metal floor so that the area where the equipment was mounted was stronger than the rest of the sheet-metal body. Such a thrust must be absorbed and attenuated by the time it reaches the small parts in the equipment, such as the elements inside a vacuum tube. This is accomplished by:

1. Rubber tires absorbing a considerable amount of shock.
2. Shock springs absorbing much more.
3. Car body having some resiliency and ability to absorb shock.
4. Shock mounts of the equipment proper absorbing most of the remainder.
5. Very small balance of shock being safely withstood or absorbed by the parts in the equipment.

The shock mounting necessary for an installation depends on the height of the equipment as compared to its base dimensions. It is also affected by the distribution of the weight so far as it affects the center of gravity. Top-heavy equipment or equipment that stands high in relation to width should not have to rely on base mounting alone. The back and if necessary the sides should be shock-mounted also. If the shock mounts are too limber, the equipment receives too much throw over a bump.

This causes wearing, breaking, or chafing of connections attached to the equipment.

The amount of support necessary from the shock mount to the car bedplate depends on how strong a bite the bolts or screws have. If the rear-trunk floor is made of sheet metal, mere screws or bolts through the same are inadequate. A car traveling at 60 miles an hour over a frost hump in the road might cause the screws or bolts to tear out. In such a case, a supplementary steel attachment plate should be provided underneath the rear-trunk deck so that the screws or bolts actually bite into that for support rather than into the thin sheet metal. If bolts and nuts are used through sheet metal without a steel reinforcing plate, then large steel washers should be used underneath to increase the bearing surface and make it more difficult for the sheet metal to tear in the vicinity of the bolt.

It is entirely feasible to solve any shock or vibrational problem encountered in normal two-way radio service on trains, planes, motor vehicles, and boats. In railroad locomotives, the high rate of speed, absence of shockproofing, roadbed condition, and discontinuity of rail sections create difficulties

Fortunately, locomotives are more strongly built than automobiles and planes so that much better attachment is possible. When ordinary shock-mounting provisions appear to be inadequate, an examination should be made for natural periods of vibration or mechanical resonance peculiar to the vehicle. All materials have resonant frequencies. If they are ignored, surprising things may happen. For example, it is possible for a person upstairs in a wooden house to cause the entire floor to vibrate merely by tapping the floor gently but consistently at a certain repetition rate, while he sits on a chair near the center of the floor.

Changing the size, type of material, or points of attachment changes the resonant frequency of the equipment so that it does not respond to the mechanical resonant frequencies peculiar to a particular vehicle in motion. It is not a question of insufficient strength of a material. It is because the material behaves like a tuning fork and responds to a certain rate of vibration. The solution is to mismatch the vibration impedances developed.

A simple way to eliminate such resonant frequency trouble is to use nonuniform material, dimensions, and points of attachment. For example, if a piece of metal has extremities every 6 inches, it will resonate and vibrate at a certain frequency, passing the vibrations from extremity to extremity. But if one extremity is 6 inches the next 4 inches, the next 7 inches, or other amounts different from that of the adjacent extremity, the vibration cannot be transmitted or passed beyond the next extremity.

In extreme cases, therefore, the material properties, placements, or attachments should deliberately be nonsymmetrical and nonidentical to prevent the transmission of any single frequency or band of frequencies throughout the unit.

In addition to shock-mounting the entire unit, the dynamotor in the transmitter has simple rubber shock-mount washers to take care of its own 4000-rpm rotating speed. On boats or vessels that roll violently at times, it is advisable to mount rotating equipment fore and aft rather than thwartships. This avoids the tendency to uneven wear and eventual vibration.

Vibration can be reduced by isolation or by absorption. In isolation, resilient cushions are used to store vibrational energy during one part of a cycle and release it during a later phase. In absorption, a mounting absorbs the vibration in the form of kinetic energy during all parts of the vibratory cycle, and yet does not release any energy mechanically, since it converts all the absorbed energy into heat. Frequently both means are used.

The degree of isolation obtained with a flexible mounting system can be expressed and computed as follows:

$$T = \frac{1}{(F/f_n)^2 - 1}$$

T is the ratio of vibration transmitted to that which would exist with solid attachment.

F is the disturbing frequency.

f_n is the natural frequency of the mounted assembly.

This equation can be analyzed as follows.

For effective isolation, the natural frequency f_n must be considerably lower than the disturbing frequency F.

Specifically F/f_n must be at least greater than 1.414 (that is, the square root of 2).

If F/f_n is less than the square root of 2, there will be a magnification rather than a reduction of vibration. This must be avoided.

If F/f_n equals 1, then a state of resonance occurs with a great increase in the transmitted vibrational forces. Continuous operation at or close to this point must be avoided.

5 Interference and Noise

How far or how strong a signal can be received through space is dependent on the signal-to-noise ratio at the receiving station. Some stations use maximum power to give their listeners a good signal-to-noise ratio. However, an installation of even a few watts power fully suffices, provided the receiving points have little interference or noise.

The average radio receiver has more amplification than it can employ without the noise finally becoming louder than the signal. When that point is reached, further amplification is useless, since further or weaker signals cannot be understood or recognized through the interference and noise. Increasing the amplification may mean no more than turning up the volume control, or driving each tube a little harder.

Complete elimination of all interference and noise is impossible in theory. It can, however, be reduced to such a negligible level that for practical purposes noise-free reception is realized. Battery-operated equipment is usually the quietest for all the voltages required. Battery current is pure DC free of ripple or pulsation. However, the exclusive use of batteries is both uneconomical and impossible for continuous service on more than minimum power. It is therefore necessary to use storage batteries which are in turn energized by a charging generator, or AC-DC rectifying equipment, or motor generator sets. These all introduce interference, noise, or induction. However, the interference or noise can also originate from many other sources.

Over-all interference and noise is less on very high frequencies than on low frequencies. It is enormously less when the equipment is of the frequency modulation type rather than the amplitude modulation type. FM is also subject to interference when and if the interference or noise has a wave form and a frequency range that corresponds to the frequency and deviation for which the equipment is designed or adjusted. Since most forms of interference manifest themselves as variations in amplitude rather than variations in frequency, FM is far superior for working through interference and noise. For example, the spark produced by telegraph key contacts can cause severe interference in the form of key clicks in an AM equipment and yet be entirely undetectable in an FM equipment.

To reduce interference and noise, FM communication can be conducted with signals that do not in whole or in any important part have the same characteristics. If FM is not available or is inadequate, as is sometimes the case, then the characteristics of the interference noise sources can be modified by filtering them out with inductance, capacitance, or both. Finally, if that is insufficient, the interference may possibly be shielded out, so that it will not cause interaction with other circuits. This also includes the use of grounding and bonding of circuits and shields.

There is a certain amount of background noise anywhere in space. There is also the tube thermal noise resulting from the thermal effects and circuit operation. As this noise is very small, sufficient amplification is possible in the receiver before the noise ordinarily exceeds the signal.

A squelch circuit is frequently incorporated in the receiver to prevent noise and interference from coming through when no transmission is coming through to override it. Suppose a receiver picks up a background noise of 25 microamperes. By adjusting the squelch control so that the receiver does not respond to anything weaker than 30 microamperes, the receiver is quiet and nothing comes through the loudspeaker during stand-by condition. When the sending station transmits a signal, it ordinarily is stronger than the amount of squelching employed. This overcomes the squelch action, and the signal comes through. Since the signal is louder than the interference and noise present, the listener hears only the signal or has little difficulty in ignoring the interference.

The squelch is an electronic circuit. There are equipments that, instead of a squelch circuit, use a small mechanical relay which opens and cuts off the loudspeaker directly or at some stage before the loudspeaker. When the interference and noise and even signal levels are below a set value, the relay remains open, and the loudspeaker is inoperative. Should a signal stronger than the value for which the relay is adjusted come through, then it energizes the relay and closes the circuit to the loudspeaker.

A squelch circuit, as well as a relay circuit, definitely reduces the maximum operating ranges, particularly with weaker signals. In effect, the signal is dammed and what passes over the dam must be depended on to conduct operations. This is permissible where the radio facilities have an excess of range or signal strength above the minimum required for satisfactory communication coverage. A good compromise used in many equipments is to provide a switch on the control unit box for switching the squelch on and off. Then when the car is near a station and has plenty of signal available, the squelch can be kept in the ON position. This gives the car quiet conditions when no communication is going on. When the car is very distant and has a very weak signal to work with, the squelch switch is kept in the OFF position. This brings in any background interference and noise but also brings the signal, weak as it may be at times. Communication then can be conducted at least 50 per cent farther except that the signal quality is distorted by interference and hiss. Sufficient intelligibility remains, however, and communication is still possible.

When the range becomes so great or the signal strength so weak that voice is unintelligible through interference and noise, communication can still be conducted a few miles farther by whistling or using a tone signal to make dots and dashes. These can be recognized even after voice is indistinguishable. Another way to increase signal-to-noise ratio is given in the section on the mobile ultra-high-frequency antenna, which appears later in this chapter.

Of the many causes of noises and interference tending to create an unfavorable signal-to-noise ratio, some may not exist or be too minor to warrant any treatment or attention in a particular installation. A police department having several makes of automobiles, or several models of the same make for the same year, or the same model and make but for a different year, may have different experiences with each category of cars.

The airplane is usually the most difficult vehicle to correct fully because it uses an internal combustion engine with each spark plug acting as a radio transmitter. In addition, it has no connection with the earth for grounding out some of this interference or the shielding. The steam locomotive on a railroad should be one of the simplest vehicles to correct since it uses no ignition system and has a metallic connection to the track which, in turn, is grounded and has a long distribution path. It is possible to eliminate radio interference if sufficient attention is given to the problem.

The sources of interference usually encountered are given here in an approximate order of importance or seriousness.

Ignition Interference. This is caused by every spark plug and the circuit breaker in the distributor head of internal combustion engines used in automobiles, airplanes, boats, and other vehicles. This interference is picked up by radiation from the vehicle's electrical system feeding the receiving antenna, or it may come through the battery or power circuit line leading to the equipment.

The solution is chiefly through the use of spark suppressors and by shielding the spark plugs and the wiring. Shielding spark plugs and wiring is rarely done, except possibly in airplanes, since it is expensive and inconvenient Spark suppressors tend to weaken the spark since they are resistors in series with the spark plug. This increases gasoline consumption and reduces engine power but not to a very serious degree. Frequently, the use of suppressors on all the spark plugs can be avoided if one suppressor is used in series with the main distributor lead only. This may reduce enough interference so that the remainder is not objectionable.

Since spark plug interference is of a vibratory character comparable with damped alternating current, it is possible to use wire-wound rather than molded-composition resistors. These wire-wound resistors have a DC ohmic resistance of only about 30 ohms for direct current but still develop a very high reactance to alternating current. In that way the spark is not materially weakened, and any noise currents other than pure DC can be attenuated. Wire-wound resistors are conceded to be superior but are somewhat more costly.

In every case, ignition interference calls for shielding leads to some extent, particularly the antenna lead from external antenna all the way

to where it connects into the set. Since the set is ordinarily a metal-grounded case, the antenna lead is shielded all the way into the inside of the equipment. A break in this shielding of even a fraction of an inch may nullify the value of the entire shielding system, as noise will be picked up again. The hood of a car should be kept closed when the engine is running; otherwise, considerable interference from the spark plugs can be detected in the receiver. Sometimes it is necessary to run a wire or a braid jumper between two metallic parts which move with respect to each other, such as the hood to the rest of the automobile body.

Generator Interference. In vehicles where a generator is used to charge the storage battery, interference becomes increasingly noticeable as the charging rate is increased. It is caused by commutator brush sparking as well as by voltage and current regulator contacts. The usual provision is a condenser to ground from the live terminal of the generator. If that is insufficient, a choke coil made up of a few turns of heavy wire able to handle the full charging current is placed in series with one or both leads. Manufacturers of generators can supply the correct choke filter for their specific generator.

Wheel Static. This is generated by the front wheels only, as they rotate on the axles. The rear wheels do not generate static since they are driven by the axle and are part of the rear axle system. The solution is to use a wheel-hub static eliminator, comprising a spiral spring which is placed between the hub nut of each front wheel and the wheel hub cover. This conducting jumper forms an electrical conducting circuit and provides a path which eliminates arcing or electrical discharge across the gap.

Static Picked Up from Atmosphere. Lightning and other electrical charges in space are most serious on the lower frequencies. It is absent on very high frequencies or microwaves It is much less pronounced on FM than on AM, although this may be partially attributable to the fact that FM operations are conducted on the higher frequencies only because of channel space requirements.

Interference When Car Is in Motion or Engine Is Racing. This means that there is faulty bonding or metallic contact between two or more parts. If two surfaces are insulated from each other by rubber shock mounting, then a copper braid jumper should be installed between the two for better bonding, thus providing a conducting path to eliminate discharge across and a difference in potential with respect to ground.

Interfering Frequencies This type of interference can be tuned in and out over part of the receiver tuning range. The solution is to insert a band-pass or a band elimination circuit comprised of a coil and condenser, which will resonate so as to accept or reject a certain frequency or frequency band.

Power-line Interference. This interference occurs particularly where overhead lines handle high voltages with poor pole insulators. Frequency modulation and very high frequencies are most immune to such interference; amplitude modulation and lower frequencies are most suceptible. If correction cannot be made at the source, then filtering circuits to smooth out or balance out these power-line interference variations are necessary.

Minor Interference. Miscellaneous types of interference may be caused by:

1. Ignition systems of passing cars.
2. Static picked up on some cement highways as car wheels pass over the separations between the sections of cement. This interference usually disappears if two of the wheels ride on the ground shoulder. It probably occurs because there is no bonding between the reinforced steel mattings in the cement of adjacent sections.
3. Neon signs and fluorescent lighting.
4. Interference from circulating ground currents. The antenna coaxial line from transmitter to antenna in the rear trunk should be grounded all the way; at each end only; or at the exact center in addition to the ends. Otherwise, circulating ground currents may be present with differences in potentials between the various grounded and ungrounded lengths. This may be detected on an AM receiver.

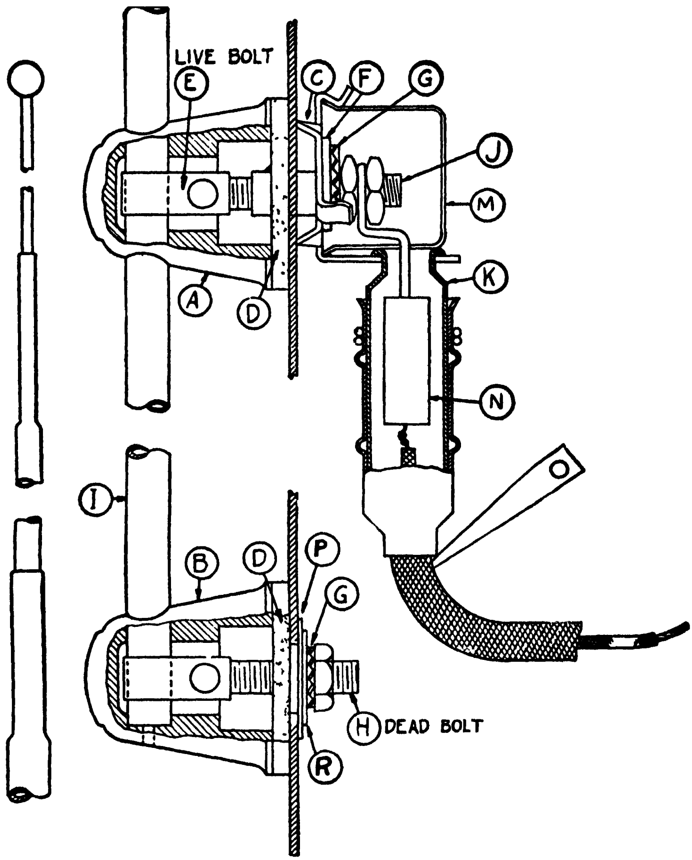
FM and high frequencies usually can cope with most of these troubles.

6 Shielded Mobile Antenna for Medium Frequencies

When automobile antennas were installed for the Maine State Police on 1642 kilocycles amplitude modulation, because of the low frequency and AM, no efforts were spared to protect the antenna from interference and noise that might be present in, or generated by, the car while stationary or in motion. Very good performances both in signal quality and statewide ranges were obtained despite the modest headquarters transmitter station power employed in most cases. Maximum signal-to-noise ratios were realized in practice, making possible ranges from 100 to 200 miles during daytime. At night, sky-wave behavior gave ranges up to 2000 miles, with intermediate skip zones of poor signal or fading.

The Motorola 206-P super cowl mount aerial was installed. This aerial is telescopic and extends from 36 inches minimum height to a maximum over-all height of 90 inches. It is made in three telescoping sections of seamless brass tubing, chrome-plated, with top section of stainless steel, guaranteed rustproof. The base section is 31 inches long; middle section telescopes out 33 inches; and top section 26 inches. Insulators provided are streamlined special BM-262 bakelite. It is equipped with a Motorola

booster unit which increases the effective signal strength up to 15 times when the aerial is matched to the frequency desired. The lead-in is completely shielded, permitting maximum utilization of volume control with minimum local noise pickup.



Motorola 206-P super cowl antenna for automobiles. (Courtesy Galvin Manufacturing Co.)

The parts as shipped in the carton include:

1. Three-section telescopic aerial with red bead on tip (I).
2. Brown bakelite insulator for upper mounting with hole clear through (A).
3. Brown bakelite insulator for lower mounting with hole on top side only (B).
4–5. Black rubber washers (D).
6. Insulated bolt (H).
7. Uninsulated live bolt (E).
8–9–10. Hexagon nuts to fit items 6 and 7.
11. Bakelite sleeve bushing (F).

12. Booster coil (N).
13. Junction box (C).
14. Junction box cap (M).
15–16. Metal lock washers (G).
17. Plain metal washer (R).
18. Bakelite washer (P).
19. Self-tapping screw to ground the shield pigtail (O).
20. Square-lipped washer to hold ground pigtail in place.
21. Scraper for cleaning connections and to assure grounding of pigtail.
22. Installation instruction sheet.

The following instructions were given to the installation personnel:

Locating Antenna. Use driver's side of car so that the aerial will clear branches and obstructions on side of road.

1. Location in relation to receiver: Length of antenna lead-in provided by manufacturer as compared to length that will be needed from aerial to receiver.
2. Location on car body side: Select position on side cowl so that aerial can be mounted vertically.

If aerial cannot be mounted vertically, tilt slightly backward, never forward. Tilting slightly backward harmonizes with slope of windshield.

Locating Insulators. Mark two locations, one above the other. One for the upper bakelite insulator (A) and one for the lower bakelite insulator (B). Keep insulators maximum distance apart, at least 10 inches.

Drilling Holes. Ascertain exact location, bearing in mind:

1. Damage to car body and effect on trade-in value; whether or not scar can be concealed when aerial is removed.
2. Whether or not too far for existing lead-in length to present or proposed location of receiver.

Drill two holes, $5/16$ inch in diameter, in the centers of the proposed locations of insulators (A) and (B).

1. Scrape down or clear all burrs caused by drilling of above holes.
2. Scrape off the sound-deadening material or any insulating paint or sediment around the top hole in order to facilitate grounding lockpoints of bracket (C).

Precautions and Final Checkup. If, when turning on the receiver, with car engine running, you hear a noise that is not present when the engine is not running or the car is not in motion, check on the following:

1. Is the hood of the car down and secured?
2. Are (C), (M), and (K) properly connected and shielded all the way by metal without any openings where induction noises may enter through antenna lead?
3. Is sound-deadening material of any amount still clinging to the metal where lock points (C) imbed into the metal, giving latter poor ground contact?
4. Is the ground pigtail properly grounded?
5. Can further grounding of shielded antenna lead-in exterior (under cotton covering) at more points en route to receiver assist in the noise eradication?
6. Is tar, rust, wax, or other poor conducting material preventing good grounding of (C) or (O)?
7. Is bolt (E) grounding to the car body directly or indirectly?

8. Is the insulation on the antenna lead-in wire poor and thereby grounding the inner wire to the shielded cover?

9. Is the connection between the booster coil and the antenna lead-in poorly taped?

10. Is the booster wire properly secured between the hexagon nuts, or is it so long that its end grounds on (M) or (C)?

11. Is (K) completely telescoped?

12. Has the shielded cover become holed, or is it partially adrift from the telescoping section?

13. Is everything tight and secure?

7 Mobile Very-high-frequency Antenna

An antenna should be designed for the frequency that it will transmit or receive signals on. It should be a quarter-wave length long if used in conjunction with a ground or counterpoise. It is then fed at the bottom (that is, voltage fed). If there is no ground or counterpoise available, it should be a half-wave length long and center fed (that is, current fed). Antennas may be multiples of a quarter-wave length but should not be less than a quarter-wave length against ground unless there are loading provisions to lengthen artificially the antenna for resonance purposes.

On the lower frequencies, the wave length is too long to provide a half-wave or even a quarter-wave antenna either vertically or horizontally run. For example, the lengths needed for an ideal antenna on the following frequencies are:

	Quarter-wave Length	Half wave Length
Medium frequency 1642 kilocycles	149.8 feet	299.6 feet
Very high frequency 39,900 kilocycles	6.17 feet	12.33 feet
Microwaves 2500 megacycles	1.18 inches	2.36 inches

Actually the antenna needs to be only about 95 per cent of these lengths due to end effects which give it a characteristic equivalent to a slightly longer antenna. However, as can be seen above, the ideal medium-frequency antenna is too long to provide on a mobile vehicle. On the other hand, microwave antennas are extremely short, so short, in fact, that they are used with reflectors. Very high frequencies have an antenna size that is usually convenient to provide.

To compute the correct antenna length for a quarter-wave antenna, which is almost universally used for very-high-frequency mobile stations, the following formula is used:

$$\text{Quarter-wave antenna in feet} = \frac{300{,}000{,}000 \times 3.28 \times .95}{4 \times \text{frequency in cycles}}$$

These figures are derived as follows:

300,000,000 is the number of meters per second that a radio wave travels in space.

3.28 is the conversion number to change meters into feet since 1 meter is 3.28 feet long.

.95 is to take care of the end effect of the antenna since it can be about 5 per cent less than actual quater-wave for a given frequency.

4 is the denominator for a quarter-wave length.

Frequency in cycles should be used if 300,000,000 is the numerator. If kilocycles is used then the numerator should be 300,000. If megacycles are used then the numerator should be 300.

Example of use: Cape Cod police use 39,900 kilocycles for their two-way AM operations. Compute the correct antenna length.

$$= \frac{300{,}000 \times 3.28 \times .95}{4 \times 39{,}900} = \frac{934{,}800}{159{,}600} = 5.857 \text{ feet}$$

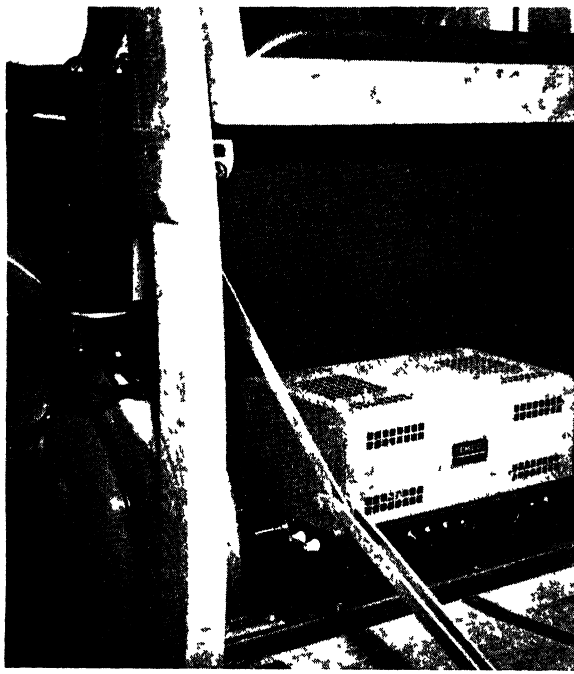
On the 30 to 40 megacycle band the mobile quarter-wave antenna will be as long as 7.79 feet at 30 megacycles, and as short as 5.84 feet at 40 megacycles. If the antenna is longer than that, some method, such as capacitance in series, is required to tune it. If the antenna is shorter, inductance in series with or without capacitance in shunt is necessary. This varies with the amount of compensation necessary.

Between the equipment and the antenna some form of transmission line must be used. The usual method is a coaxial cable. A coaxial cable in its simplest form is a shielded ignition wire comprised of an inner conductor, an outer metallic sheath, and something to keep the inner conductor concentric or equidistant on all sides with respect to the sheath. The latter spacer must be nonconducting. The purpose of the coaxial transmission line is to conduct the energy from transmitter to antenna with minimum loss and to prevent the transmission line itself from acting as the radiator along with, or instead of, the antenna. Standing waves, which result if the transmission line acts as the radiator, must be prevented, as such radiation would be inside the vehicle and shielded out. The power must be conserved entirely for the antenna proper. If the coaxial cable sheath is not in good metallic contact with the transmitter cabinet at one end and with the body of the car at the other end, where the inner conductor connects to the antenna, then standing waves will occur. Very little signal strength and range through space to the receiving point will then be obtained.

To locate the mobile antenna so that it will be convenient and less likely to strike obstacles, it should be on the left rear side of the car, close to the rear trunk, starting from about bumper level. That side is toward the center of the road where there is less likelihood of striking low-hanging branches as the car moves along a highway. But for maximum signal

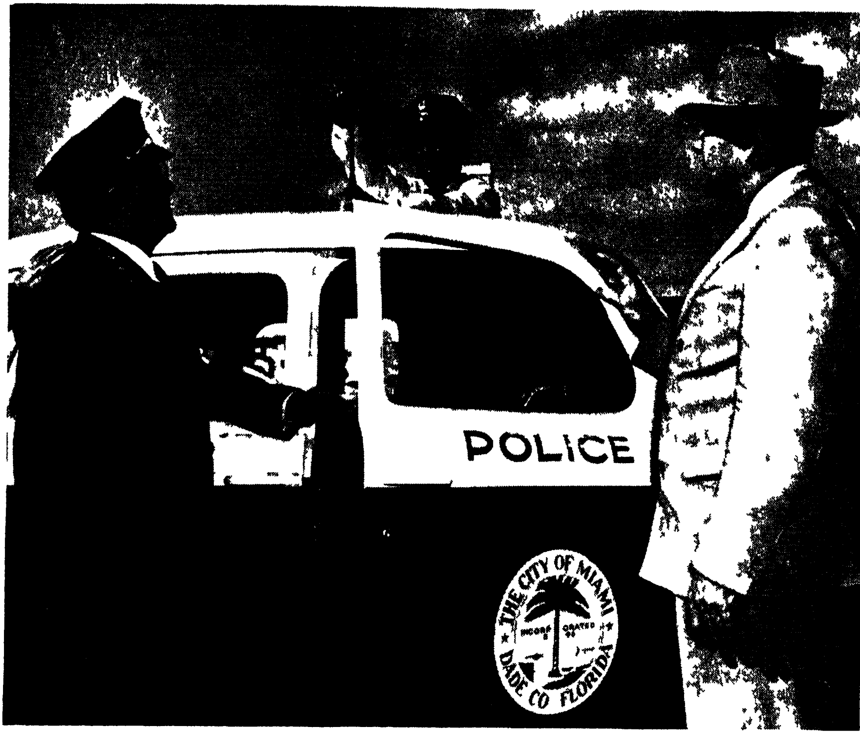
strength and range in all directions with good uniformity, the antenna should be mounted on the roof of the car in approximately the exact center. The reasons for this are not generally known and are interesting.

If the antenna is mounted at bumper level at the left rear side of a car, as is usually the case, the signal strength is about four times greater in the direction of the right front wheel. If the antenna is mounted at right rear of the car, the signal strength is that much greater in the direction of the left front wheel. If the antenna is mounted on the front, the signal



Temco model 25K long-range, two-way mobile equipment used by United States Border Patrol and Mexican War Department.

strength is strongest to the rear. If the antenna is mounted on one side of the car, the signal strength is greater toward the opposite side. In other words, the metal car body acts as a counterpoise or distributed ground. In the direction away from the metal, there is no counterpoise or distributed ground, and only about one-fourth the signal strength prevails. This is the common experience of all police radio cars on very high frequencies. A difference of 50 per cent in range and signal strength is possible when the car body lies between the fishpole and the station directed to. This is opposite to what the novice would expect.



118 mc mobile roof-top antenna (Courtesy Galvin Manufacturing Co and City of Miami, Fla)

To maintain this 4-to-1 advantage in all directions, the Connecticut State Police and later many other departments decided to have the antennas located in the center of the roofs of their cars. Tests made by them and subsequently verified by many others showed that the 4-to-1 advantage prevailed in all directions and a very uniform pattern was obtained. For example, where a car might work a horizon of distance to the rear and a horizon and a half of distance to the front with a bumper antenna, the horizon and a half of distance could be maintained in all directions with little falling off when a roof-top antenna was employed.

An accompanying photograph shows the placement of the antenna on the roof. A spring base is provided so that the antenna may bend in any direction if it encounters an obstacle. These antennas may be damaged more readily, but some users believe it is worth the inconvenience and damage to get the extra range.

If an antenna breaks after a period of usage, or after a collision with branches, it is seldom a total break Enough usually remains to provide

effective though inefficient communication, particularly if the antenna circuit in the transmitter can be retuned for the new antenna length.

Another advantage of roof-top antenna locations is the extended radio horizon that can be obtained. Where both stations have their antennas at the same identical levels and with flat terrain other than actual curvature of the earth, this computes as follows:

	Each Car's Horizon	Miles Car to Car
Bumper antenna height above ground, 8 feet maximum	1.4 × square root of 8 = 1.4 × 2.73 = 3.82 miles	7.64
Roof-top antenna height above ground, 12 feet maximum	1.4 × square root of 12 = 1.4 × 3.46 = 4.84 miles	9.68

This is on the basis of horizon alone, exclusive of the 4-to-1 signal advantage in the best directions versus the poorest direction in the case of the bumper antenna.

8 Storage Battery Drain and Generator Charging

A dead storage battery in a car at night is a problem that frequently arises in a new system. In addition to running the two-way radio equipment, the same storage battery has several other tasks to perform. The following estimated loads are common to radio-equipped automobiles.

	Amperes
Constant load for:	
Car ignition system (about)	2
Operating radio receiver and keeping transmitter tubes warmed up ready for instant transmission	8
Intermittent or night use for:	
Dimming headlights	4
Brightening headlights	12
Searchlight	8
Car heater	2
Defroster	1
Cigar lighter	30
Radio transmission fully modulated	up to 50
Car starter	300

Allowing for night, day, summer, and winter, in motion or parked, the battery should be connected to a generator which supplies it with at least 30 amperes when the car is in motion. If the car is parked more than operated, a 40- or 50-ampere charging generator is recommended.

Ordinary passenger-car generators are not satisfactory for municipal police departments because such cars cruise at slow speeds. They require generators that will charge about 20 amperes if the car is moving at 10 miles an hour. State police cars can usually cruise at a higher rate of speed and can often use the modern standard automobile generator. However, most modern departments, both municipal and state, usually try to obtain

storage batteries of the largest size and generators having heavy charging rate for the cruising speeds used in their work. The tractor-type battery of from 120 to 180 ampere hours with a 6-brush 50-ampere charging generator is typical. To use such an oversized generator requires a very good voltage and current regulator, as the battery may overcharge during summer months in the daytime. This can cause buckling of the battery plates. Some radio equipment may be provided with a thermal relay which opens up the circuit if the voltage gets too high or the current passing through it is abnormal. It is sometimes necessary to disconnect the thermal relay, since it may defeat its purpose by opening the circuit merely because of a high charging rate and consequent peak battery voltage. At such times it is so near the threshold of operating-not-operating the thermal relay that equipment will cut in and out or have to be started up again for no reason other than the behavior of the thermal relay. Fuses are simpler and not so critical.

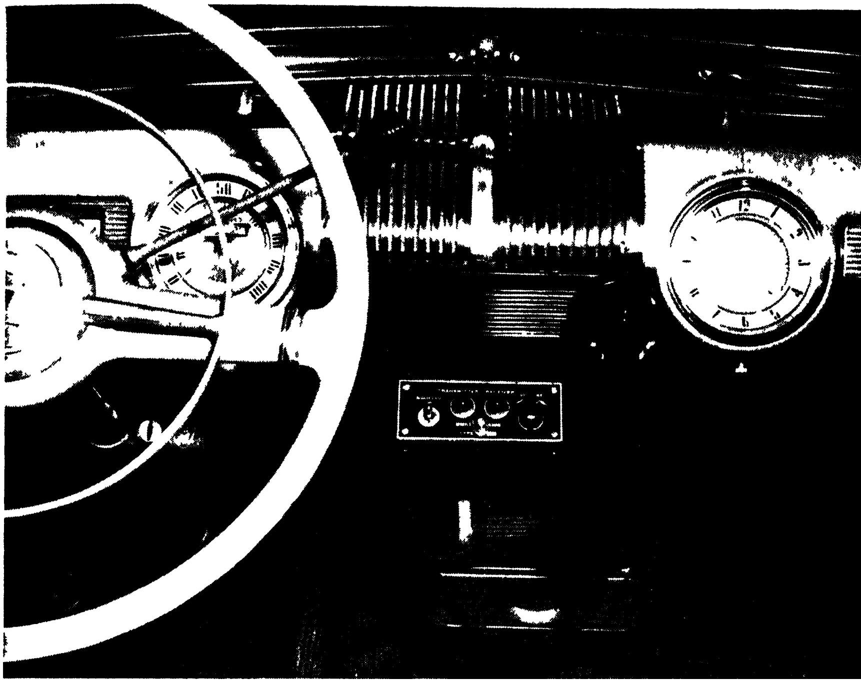
A larger storage battery is desirable if the charging rate is high when the car is in motion and must deliver a considerable load while the car is stationary and the battery is not charging By careful use of the equipment and by driving the car at speeds which give the maximum charging rate, the standard battery and generator of ordinary passenger cars can suffice; but this would require that the car be in motion and the generator charging when the radio equipment is operated for any length of time. It would not tolerate frequent use of the car starter.

A battery has less power available in cold weather than in warm weather. It decreases about ¾ per cent per degree Fahrenheit decline or about 1.3 per cent per degree Centigrade At such time, in addition to having less available battery power, cars are much harder to start and heaters must be kept running; also, the longer period of darkness requires greater use of headlights. Therefore, it is necessary to base the battery size and the generator on winter requirements. Mobile stations in police service throughout the United States encounter temperatures as high as 100 degrees Fahrenheit and as low as 50 degrees below zero Fahrenheit Occasionally these extremes are exceeded The battery in mobile service may have a life of 12 to 36 months The generator may be good for several years, other than taking a cut on the commutator and replacing the brushes annually. The voltage-current regulator should be checked whenever there is a possibility that it is misbehaving. Cars have been known to overcharge and ruin batteries because the regulator cutout failed to function. Also, there have been cases where a car should have been charging 40 amperes and on investigation was found to be charging only 5 amperes. It is the function of the regulator to take care of such situations.

9 Installation of Mobile Equipment

·To install a mobile unit that is good-looking and works well is only part of the job. The unit must be so located that it can be conveniently uncovered for servicing and also can be easily removed without dismantling the vehicle. It should be possible to transfer the unit from one vehicle to another without having to chop off cables or chisel off fastenings, thereby requiring new items to reconnect the equipment. While both good performance and good appearance can be provided, the former is more important and has the right of way. Many "bread-board" models, particularly among amateurs, outwork the fancy final model. Therefore, when installing mobile radio equipment consider the following:

1. The items not required for the control and use of the receiver and transmitter should be located out of the sight and reach of unauthorized and unqualified persons. Locate the unit in an unimportant space; in an automobile, this is the rear trunk.
2. If locating a unit in the rear trunk, do not place it in the middle of the deck, as there would be little usable space remaining for other storage. On the other hand, do not crowd the unit into a corner so that the back or sides of the unit cannot be reached for cable disconnection or cover removal. The aim is to provide maximum remaining space without preventing convenient servicing.
3. Provide enough room atop the unit so that the cover can be lifted off the chassis.
4. Locate the unit so that it can be tuned without too much crouching, body twisting, and head banging by a technician.
5. Locate the unit so that its cover can be taken off and even the entire unit be removed from the bed mounting plate conveniently.
6. Do not allow the unit to interfere with the removal of the spare tire in an automobile compartment.
7. Make sure that the spare gear in the rear trunk will not slide or slam on the equipment when the car is in motion under the most difficult service conditions.
8. Locate the unit so that the coaxial run to the antenna will be of the shortest length. Some technicians prefer to make it quarter-wave length even if there is some slack. This is a debatable question. Good results are obtained both ways.
9. Never let a cable run through a metal hole without chafing protection, such as rubber grommets placed in the holes.
10. Use lock washers so that nuts will not loosen from the bolts.
11. Make sure the support for the bedplate is strong enough to stand the thrust of a vehicle in motion. If not, reinforce it with a steel plate.
12. Do not let screws or bolts pierce into the gas tank or gas line under the rear-trunk deck. Check underneath to make sure there will be no obstructions.
13. Before drilling a hole in an automobile body, look back of the spot selected to make sure the hole will not be in line with some large body member.
14. Remove the rubber matting and bond to the metal or use a metallic braid jumper from the metal unit cabinet to the car deck or body.
15. Allow enough space when locating the unit so that the hands of the technician will not get chafed and bruised when servicing.



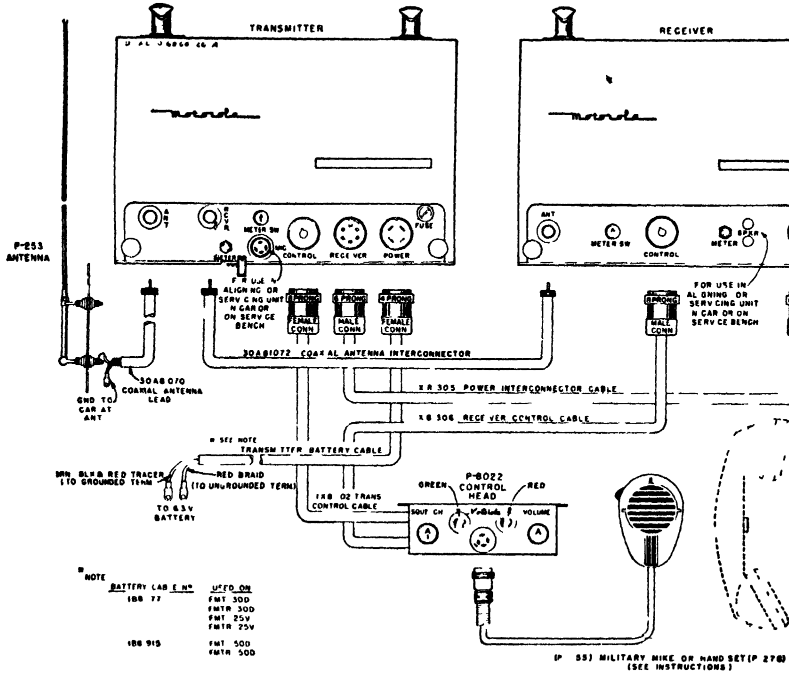
View in driver's compartment showing control unit and microphone (Courtesy Connecticut State Police.)

16. Provide a rear-trunk light for servicing in the dark, or a miner's head lamp, as a flashlight usually requires the use of one hand.

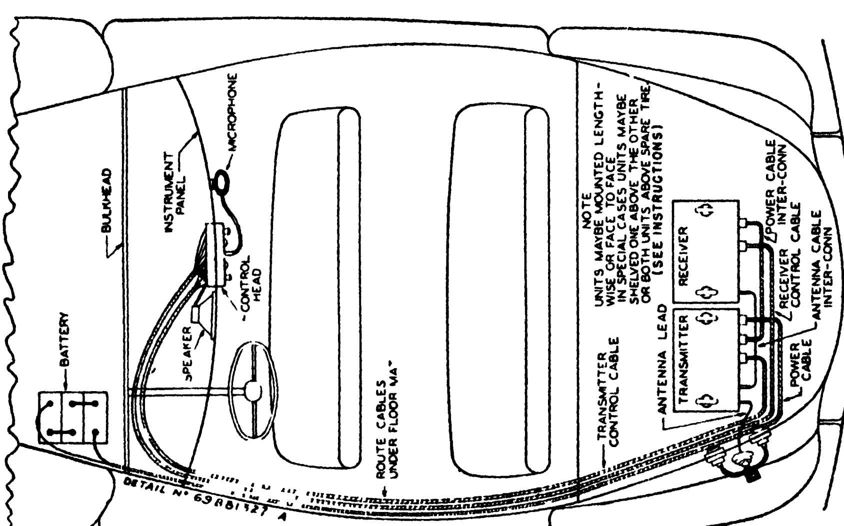
17. If the mounting deck is uneven or has some contour, level it off. If necessary to use wood or insulation to do this, run a heavy flexible strap from the base plate to the grounded body to get the same effect as if it were resting directly on metal.

18. If the equipment is mounted on a wooden shelf above the spare tire, use a metal plate and ground it. The thickness of this plate does not matter, as it is for electrical contact rather than structural strength. It can be of sheet copper or of galvanized iron. Bond it to the car in several places, making the bonds short and direct.

19. The dynamotor in the transmitter and the vibrator in the receiver are polarized, and the positive and negative battery connections must be correct, or they will not work in most cases, or the dynamotor will work in reverse. Check the battery to see if it has positive or negative ground. Most mobile installations have only one wire running to the battery from the equipment, with return circuit through the metal body back to the battery. If there is any question about the return circuit, use a second wire for that purpose. The larger the diameter of the wire, the less voltage drop there will be, and the equipment will get more nearly the maximum possible performance of the battery voltage. With a 10-watt AM set or a 25-watt FM set, the voltage drop is about half a volt during transmission and about a tenth of a volt during reception for a size-8 battery lead from a stor-



Transmitter-receiver cable layout (Courtesy Galvin Manufacturing Co.)



Proposed complete car layout (Courtesy Galvin Manufacturing Co.)

age battery under the hood with equipment in the rear trunk. The voltage drop can be further reduced by using larger wire. A drop of 1 volt is serious, since there is only a 6-volt storage battery to begin with; it represents too large a percentage of the total source.

20. Mount the mobile antenna so it will be least likely to encounter interference. In an automobile, it encounters least obstruction and collision with low-hanging branches if mounted on the driver's side of the car, the side toward the center of road not the side of the road.

21. Mount the mobile antenna on a plate attached to the bumper, so that holes need not be made in the body of the car. Bring the lead in under the body so the hole does not show but as high as conveniently possible so that it will be less subject to water entry and exit. Scrape the paint and covering off the car metal wherever it serves as a ground or return circuit.

22. Never let the coaxial cable sheath float. Make sure it is grounded to the transmitter cabinet at one end and the car body at the other end. En route it should be either ungrounded or grounded at the exact center so that any circulating currents induced in the sheath will not have two different potential paths with a voltage difference between the two, causing interference on the receiver.

23. Never jeopardize a fine finish on an automobile, particularly where it is streamlined, by drilling the hole directly. Always use a center tap to make an indentation to guide the drill; otherwise, the drill will wander and scratch a large portion of the body and leave permanent scars.

24. Protect the cables running from front to rear of a vehicle. If necessary, provide a metal channel cover or guide to prevent the cables from being stepped on; to prevent the seat from striking the cables directly; to prevent any slackness which might cause the cables to get caught in the door; and to prevent an adjustable front seat from chafing the cables.

25. Cables exposed under the vehicle should be insulated and protected sufficiently against water, slush, or mud, and should be run in the channel iron and strapped so that the cable will not rub against the ground or against anything on the ground that the car might ride over.

26. Mount the microphone lower than the driver's face and eyes, so that in the event of a collision it will not strike him in the face if knocked out of the holder.

27. Do not cut the cable shorter than the maximum length required for any car, even though a surplus exists, for a coupe, for instance. Cars to which the set may be transferred later may require the maximum length.

28. When holes must be drilled, make them where they will be least visible and of such a size that can be plugged neatly with attractive insertion caps.

29. If time is important when installing equipment, two men can work simultaneously. The average mobile station can be installed by one competent man and a helper in eight hours, frequently much less, if it is the second or subsequent car of an identical type. The time can be held to four hours if all materials are ready and everything has been planned in advance. It is possible to speed up the job by having different individuals handle the following details simultaneously:

(a) Stringing cable from battery to rear trunk and from driver's compartment to rear trunk.
(b) Drilling holes for antenna and cable passage and parts mounting.
(c) Mounting units in front compartment, such as control unit, microphone stand, and loudspeaker.

(d) Mounting units in rear trunk.
(e) Mounting the antenna and running it to the transmitter.

30. In connecting the power lead to the live side of the battery, do not connect it directly to the battery, since it gathers corrosion and will eat away. Instead, loosen the lug on the starter and attach the power lead on the same lug, where the battery lead is coming from the battery on the starter. The starter lug then has two wires attached to it.

31. In a wooden vehicle, such as a station or beach wagon, having no convenient ground, mount a mesh screen or metal sheet on the floor and ground it to the car frame anywhere near by.

32. Bond and ground all equipment to the car body, including the control head and loudspeaker. Frequently that may be the return circuit, and it will not operate or will operate intermittently if not bonded and grounded.

33. If there is any possibility of water getting into the rear trunk, this must be prevented to avoid harming the equipment. It is surprising how many cars have leaky rear-trunk doors or hoods. The leaking is usually from the top seam due to a faulty rubber gasket. The channel may be absent or may have been so designed that the water is not led to a point where it runs onto the ground. The water may run, instead, along the seams, and several inches of water may accumulate in the rear trunk during a rainstorm. Under such conditions, equipment will rust and be soon ruined. If there is any possibility of leakage, mount the equipment on an elevated bedplate support so that it is a few inches higher than the rear-trunk deck and protected from deck-surface moisture. This is rarely necessary or justifiable in practice. It is better to remedy the defect; otherwise, leakage will also harm anything else in that compartment.

CHAPTER FIVE

THE FIXED STATION

1 Headquarters Station

The fixed station ordinarily receives much more usage than the mobile station. Usually, one fixed station communicates with many mobile stations and gets as much usage as all those stations combined. It may be in twenty-four-hour service day after day and year after year. The mobile station, on the other hand, is usually in intermittent service, averaging only a few hours a day. Some mobile stations, such as a transcontinental railroad train, receive much heavier service. Even so, part of the time is spent in terminals or in routine overhaul, during which time the radio equipment is not operating.

The fixed station usually gets more attention in the way of power, antenna facilities, and expenditure. It can be equipped more elaborately and more ideally, since the antenna system, space and size dimensions, weight, power supply, and equipment care are much easier to provide.

The fixed station is usually controlled at an administrative or dispatching point for a police or fire department, railroad, transportation firm, or other user, which may be in a poor location for ideal radio communication, such as the highly congested business district of a city. Cities and important headquarters communities are frequently not located in the geographic centers of the areas which they serve or represent. Seldom are the locations ideal for radio coverage of their hinterland. For example, the fixed station control point may be in a valley surrounded by hills or by mountains, or it may be virtually at sea level, or it may be along a river or lake.

When the coverage required is local, such as a police station communicating with cars located within a city, the equipment can usually be located on or in the same building from which it is controlled. If the coverage is very extensive, such as an entire county, a state police district, or an entire railroad division, remote control facilities are usually necessary. This is particularly true if communications are conducted on

the very-high-frequency or microwave bands where no long-range sky-wave reflections are possible.

By remote control the control point gains the range and efficiency that is possible from the highest and most favorable communication point in the communication zone involved. This is done either by using a pair of telephone wires between the control station and the equipment location or by radio relay.

The fixed station controls the range and efficiency of the two-way system by virtue of its location, antenna design and location, and hours of service. Usually, it has more powerful transmitting equipment but approximately the same type of receiving equipment as the mobile station, except that it is associated with a much superior antenna system. The quality and stability of fixed station equipment are better because the equipment undergoes no shock or vibration and the power supply is always very stable and of unlimited capacity.

If a system is to be truly 100 per cent two-way in operation, there is actually little point in providing headquarters with larger or more powerful equipment than is furnished to the mobile station, as this ordinarily results in the mobile station being able to receive farther than it transmits to headquarters. It may be of some additional value to the mobile station to receive a louder signal, as this compensates for distractions of travel and noise from the vehicle's power plant, rotating components, and uneven roadbed. Many systems are obtaining satisfactory performance by using identical equipment for both fixed and mobile stations so far as power and sensitivity are concerned, differing only in the type of power supply employed.

Any improvement in antenna design and location by either the fixed or the mobile station is of value to the other. For example, if headquarters has a better antenna location, it transmits better and farther. It also receives better and farther from any other station on that frequency of operation Therefore, no expense should be spared in selecting and installing the best antenna system. If economy is necessary, it should be in the transmitter power but never in the antenna system. This is particularly true on very high frequencies or microwaves. One watt of power with an efficient high antenna system will outperform in both range and signal strength 1000-watts of transmitter power fed to a poor antenna system having little elevation.

The rule always to follow when funds are limited or range requirements are abnormally large is to concentrate on the antenna. You can buy equipment that virtually requires little more than plugging some connections together or into a wall outlet. but an ideal antenna system should be designed and installed under the supervision of a qualified

person. Much of the amazing performances obtained by radio amateurs with very modest equipment can be attributed to carefully planned antenna systems.

2 Design Differences between Fixed and Mobile Stations

Basically, fixed and mobile station require the same items of equipment, which, if desired, can be identical in every respect, but in practice they differ.

The transmitter at the fixed station can have any power desired, being limited only by the purchaser's pocketbook, as space and power supply are not limited at the fixed station.

The power supply is usually obtained from commercial lighting or power circuits already in the building. This is converted via a rectified power supply as required for the equipment. The rectifier is usually incorporated within and appears to be part of the transmitter and the receiver. Dynamotors in transmitters or vibrators in receivers, as described for the mobile station, are not used. The transmitter and receiver have additional tubes to take care of the rectifier circuits. The transmitter may have several rectifiers, each taking care of certain circuits only. Except in the lowest-powered transmitters, the final power stage of the transmitter will have its own high-voltage rectifier system. The preliminary stages in the transmitter, particularly the oscillator which generates the correct frequency with its associated frequency multiplier stages, have a separate high-voltage rectifier. This promotes frequency stability and better signal quality, and divides the burden of the circuit power supply.

The antenna can be of half-wave length in free space or of quarter-wave length working against ground. The ground can be the earth or a counterpoise rod system, or, in place of either, it can be the coaxial type having a quarter-wave radiator against a quarter-wave skirt directly below it.

The transmission line is much longer between the transmitter/receiver and the antenna line. Therefore, in the case of coaxial cable, it is of larger dimension in order to handle more power and to do it with less transmission loss per unit of length.

The transmission line is subjected to a variation of temperature and weather enroute from inside a warm building to a cold and exposed external antenna location, which, has a tendency to cause condensation inside a hollow coaxial transmission cable. This condensation causes arcing between the metallic sheath and the inner conductor across the spacing insulators between the two. In time it will electroplate a layer of copper between the two and cause the line to short-circuit or to have a measurable resistance between the two instead of infinite resistance. It

Typical remotely controlled headquarters station for two-way FM communications The building is of steel fireproof structure with ventilated louvres Inside can be seen the Link 250UFS transmitter and two Type 12-UF receiving channels. One channel is for barracks to barracks on 39,500 kilocycles. The other channel is for barracks to car on 39180 kilocycles. On the mast can be seen the automatic photocell light-control device to switch mast lights on during poor visibility and to switch them off during good visibility. The station operates automatically and is unattended. A pair of landlines run back to the barracks from this high vantage location a few miles away. This is standard for Connecticut State Police, varying only in mast heights and distance from barracks, depending on the elevations available and adjacent mountainous obstructions. (Belthany District, Courtesy Connecticut State Police.)

is therefore necessary to provide means to keep the interior of the transmission line dry. This is done by keeping dry nitrogen gas under a few pounds pressure in the line. It can also be done by providing a dehydration units that employs a silica gel cartridge. A pound of silica gel removes the moisture from 400 cubic feet of free air at average temperature and humidity. The silica gel method is somewhat more popular if the transmission line cannot be kept gastight.

The fixed station may have parallel control facilities so that more than one point can listen, transmit, or do both. In South Portland, Maine, for example, the equipment is located at the police headquarters. Both the

police and fire departments use the same equipment. Each has a microphone, loudspeaker, and control box to listen and transmit on the same transmitter, receiver, and antenna system, even though they are across the street from each other. Any number of microphones and/or loudspeakers can be provided within several hundred feet of the fixed control point. They are merely connected in parallel with each other in such a way that the circuit impedances are matched to the equipment as would be the case normally.

3 Components of a Fixed Station

The fixed station components differ most radically from those of a mobile station if remote control facilities are necessary. In the case of radio relay control, the fixed station may be the equivalent of one large station and one small station combined, or be a station and a half.

The following major items may be found in a fixed station:

1. Transmitter, including microphone.
2. Receiver, including loudspeaker.
3. Control unit. This includes microphone and loudspeaker if the transmitter and receiver are operated by remote control.
4. Tower or mast of considerable height.
5. Guying or foundation system for such a tower or mast.
6. Coaxial transmission line between transmitter/receiver and the antenna on mast or tower.
7. Mast or tower lighting system as warning to airplanes.
8. Landlines to a remote control location, if necessary. Or this may be a radio relay link utilizing an additional receiver and transmitter of less power and usually of a higher frequency.
9. Parallel controls, microphones, and loudspeakers so the same equipment can be utilized from more than one location.
10. Emergency gas-driven or battery-operated power plant in the event normal power facilities fail.
11. Auxiliary mobile station for standby purposes when main equipment is off the air for any reason.
12. Special furniture to house the controls.

The frequency measuring equipment, spare parts, tools, and the like, are usually located at the fixed station to serve that point and also the mobile units which have occasion to stop there.

4 Antenna System for Fixed Stations

Antennas for fixed stations have three parts:

1. The antenna proper which radiates the high frequency-modulated electromagnetic waves from the transmitter into space.
2. The transmission line which conducts the high frequency-modulated energy from the transmitter to the antenna, or from the antenna to the receiver.

3. The ground system without which performance usually would be very poor.

Highly elevated antennas definitely increase signal range and strength. Obstructions can be cleared and the total horizon extended if either or both the sending and the receiving stations employ elevated antennas of reasonably good design.

The mobile station must travel over areas where conditions may at times be poor, fair, good, or excellent. The fixed station must provide the extra strength and range needed by either or both stations. The fixed station does this by having its antenna located on a vantage point even if this necessitates remote control to some hilltop, mountain peak, or very tall building.

A high tower or mast in the case of ultra high frequency or microwaves is merely the equivalent of a high hill. For example, a simple mobile antenna on a 300-foot hill outperforms in range and signal strength the finest antenna and transmission line utilizing a 200-foot tower for elevated support. The mobile station often travels along highways at elevations above sea level far greater than that of the fixed station and, at such times, has a greater range than the fixed station, regardless of the difference in power for their respective equipments.

A good tower or mast may cost as much as the rest of the equipment combined if both the materials and labor have to be contracted for. The guyed type of tower is usually safer and less expensive but requires much more land because of the guying system. The self-supporting type of tower is built more ruggedly, with considerable distances between the legs at the base, and it tapers toward the top. The latter type requires special design and erection, which in virtually every case is beyond the capacity of the purchaser's organization to undertake; it usually must be contracted for with an engineering or structural steel firm. Such a tower costs from $5 to $15 per foot of height. The guyed type (described in the next chapter) can be erected for from $2 to $10 per foot including all costs, depending on the height, ruggedness, guying system, and whether the purchaser does any of the erection himself.

In two-way radio work it is customary to keep the tower height below 200 feet to simplify meeting the Civil Aeronautics Administration lighting requirements. It should not be necessary to exceed that height in most cases. Should the horizon and range require more height it is advisable to study the possibilities and feasibility of using remote control to some convenient near-by hilltop or mountain. If such a hilltop or vantage point is available, it means an absence of obstructions and maximum horizon is gained. Community two-way systems frequently gain sufficient coverage by having the antenna located on the roof of the fixed station

building, usually atop a single section of mast that need not be over 25 feet.

In the fixed station there is usually a rather long run between the equipment and the antenna. The longer this line, the more power is consumed in sending energy from transmitter to antenna. For example, a ⅜-inch coaxial cable, which is commonly used in low-powered fixed stations, loses 14 per cent of its power every hundred feet. With 10 watts and a 200-foot run to the antenna, the first hundred feet would use up 14 per cent of 10 watts, leaving 8.6 watts. The next hundred feet would use up 14 per cent of 8.6 watts, leaving 7.396 watts by the time it reached the antenna. It is less if a larger-sized coaxial line is used; for example, a ⅞-inch coaxial cable, which has a loss of 3½ per cent per hundred feet. The above figures are based on actual experiences encountered by the Maine State Police on 39,900 kilocycles. Their longest transmission line is at WSWD, Wells, Maine. It is 430 feet long, from the transmitter/receiver in the control room to the antenna atop a 195-foot tower. A longer transmission line or a smaller-sized line also results in less received signal strength but not necessarily in markedly less range. Range is a function of the horizon, whereas signal strength is associated with power and efficiency.

5 Range Control

If only a small amount of additional coverage is required, it is obtainable by raising the antenna height at headquarters. It is also obtainable by equipping the entire system with frequency modulation equipment instead of amplitude modulation.

Generally speaking, the procurement of additional range by increased transmitter power is the most expensive way and is only partially effective. It has some value on sky-wave frequencies but not very much on the higher frequencies which utilize only ground-wave components.

To double the signal strength regardless of range, the power must be squared rather than doubled since it falls off as the inverse square of the distance. Beyond the radio horizon it falls off much faster than that and is not accurately computable. For example, if a station has been using 10 watts power and wishes to double its signal strength within its horizon, it must employ 10 times 10 or a total of 100 watts to do so. If it employs 10 plus 10 or a total of 20 watts, all it does is increase the signal 3 decibels or 3 units of sound difference. A gain of 3 decibels is not very important in increasing the range; in practice it might provide possibly a mile extra range for an average system. To double the signal strength of a 1000-watt station would require the use of 1,000,000 watts. This amount of power has heretofore been considered prohibitive and uneconomical.

As a transmitter increases in power rating, its operating and maintenance costs skyrocket. So does its initial cost. For example, to use 1000 watts power, it must be built up through several stages or tubes, starting with an oscillator of 1 to 5 watts. The final tube determines the power of the transmitter. However, the oscillator cannot control such a large tube; for example, it may not control more than five to ten times its own output. There have to be stages known as buffers, drivers, or intermediate amplifiers. In the case of amplitude modulation it must be associated with an audio system likewise developed from a weak microphone input to sufficient power to modulate the 1000 watts. Each successive stage requires more and more filament and plate power, and larger and more expensive tubes than the previous stage.

It is cheaper to use low power and a higher antenna. The antenna has little maintenance expense and consumes no power other than a small tolerable transmission loss. The receiver, however, should be the best available. It should employ one or more stages of radio-frequency amplification in addition to any intermediate- and audio-frequency amplifiers it may contain. Even the best receiver on the market is usually within the purchaser's ability to afford, as it costs about the same as the lowest-powered transmitter. The difference between a high-powered transmitter and a low-powered transmitter, in practice, at a receiving point may mean no more than a difference in volume control setting. Two-way radio communication works satisfactorily for normal quality speech. It does not require facilities capable of handling with utmost fidelity and frequency response every instrument of a huge philharmonic orchestra.

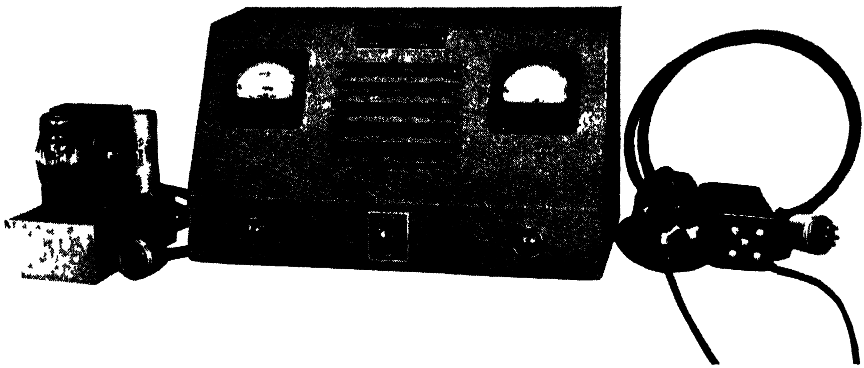
The three ways to get more range and signal strength in order of results are:

1. Greater antenna height—the preferred method always.
2. Better receiver sensitivity and amplification.
3. Increased transmitter power. This is most useful on low frequencies and least pronounced on very high frequencies.

6 Remote Control by Landline

The remote control unit is designed to provide control of a radio transmitter and receiver over a two-wire telephone line, which may be privately owned or may be leased from the telephone or telegraph company. A typical cost for such a line is about $3 a mile per month. Remote landline control is used in many important systems today for distances up to several miles. If the distance exceeds 10 miles, it may be preferable to employ a radio relay.

Landline remote control requires a metallic circuit capable of carrying direct current voltages up to 100 volts at 10 milliamperes. A typical



Remote control landline equipment. (Courtesy F. M. Link)

requirement is 65 volts at 8 milliamperes. The longer the line, the greater the voltage drop will be. Finally, at a distance of about 10 miles, the line drop is substantially great, and it becomes advisable to shift to radio relay between the control point and the antenna location.

Ordinarily, the transmitter and receiver equipment at the antenna location has its tube filaments lighted at all times. Usually, only one receiver is utilized. If more than one receiver is utilized, and if the filaments must be turned on and off, then more than one pair of wires is required. Certain multifrequency equipment is used in aeronautical and marine stations by which one station can shift to a choice of frequencies. Then many wires are used between the controls and the equipment. For example, a certain marine equipment designed for 6 different wave lengths actually employs 17 wires in the control cable. In that case, it usually is employed for a short distance, such as 50 to 100 feet, although it can, of course, be designed for a much longer distance.

A typical landline remote control unit, as used in two-way radio for a state police station, performs the following functions:

1. Turns on the high voltage and thereby energizes the transmitter at the antenna location when the microphone switch is closed at the control point.
2. Amplifies the voice uttered into the microphone at the control point sufficiently to compensate for diminution in signal strength in traveling along the metallic circuit, so that it will be sufficient to modulate the transmitter.
3. Cuts off the transmitter, when the microphone switch is opened, by releasing the switch at the control point and automatically cuts the receiver into the landline circuit. The antenna then energizes the receiver instead of the transmitter. The receiver output is amplified and operates a loudspeaker at the control station.

To perform these functions, the control unit comprises the following items:

1. Microphone amplifier.
2. Receiver amplifier.
3. Push-to-talk handset or microphone.
4. Loud speaker.
5. Self-contained power supply within the control unit.
6. Receiver volume control.
7. Two pilot lights on front panel. A green light to show that the equipment is turned on in the standby receiving condition. A red light which only comes on during transmission.
8. Relay to transfer power from receiver amplifier to microphone amplifier during transmission.
9. Optional features such as a tone signal to attract attention; a monitoring circuit to receive by radio method a signal back from the remote antenna location for signal check; and various semiaccessible adjustment controls that are usually left preset.

Basically, a remote control unit is an audio amplifier to boost the microphone output or the receiver output to a level sufficient to overcome the transmission loss over a lengthy metallic circuit.

Where more than one receiver is employed and only a single pair of wires is desired, the two receiver outputs are fed to a common loudspeaker. A typical case is a headquarters station transmitting on one frequency while the cars employ another frequency. This would be the case in duplex operation and where the fixed station wanted to monitor or to communicate with other fixed stations in the system. Both receivers feed their outputs to the same telephone line back to the control point. The same loudspeaker and amplifier handles the output of both receivers if a single landline pair is used. Either receiver can be heard. Should they both be receiving at the same moment, the loudspeaker brings both in. However, in practice, the fixed station does not break in when the mobile station is coming through, or vice versa, except in an emergency.

The capacity of a radio channel is very great, since communication is conducted by voice, which is ten times faster than telegraphy. A transmission rarely is one minute in length; that would be sufficient for 150 to 200 words of communication, equivalent to about ten to twenty telegrams. A well-organized communication setup transmits what it has to say in five to ten seconds. Communication is usually so positive that it is seldom necessary to establish contact first with the mobile unit. It is taken for granted that the mobile station is on the job and will promptly acknowledge at the end of the transmission. The call up may be only one or two words; the text can be a coded signal of two words; the acknowledgment, one to five words. Fifty mobile stations can work with one or more fixed stations on a single channel with amazingly little congestion. Being inconvenienced more than five seconds because someone is using the channel may never occur. If it does occur, the station being incon-

venienced can break in, and headquarters can stop the other station and change over to find out the reason for the interruption.

7 Radio Relay Stations

Although landline and radio relay may displace each other or have overlapping functions, there are situations where landlines are unsuitable, such as when the controlled location is on an island or on an isolated mountain that is inaccessible at times or is beyond efficient and economical distance for wire control.

Radio relays permit the controlled location to be any distance not exceeding the radio horizon. This can conceivably be up to 100 miles airline for a mountain location exceeding 5000 feet elevation. It makes little difference whether the distance is 10 miles or 50 miles so long as the horizon is not obstructed. The signal attenuation because of increased distance is not excessive within the horizon, since the receiver has sufficient signal-to-noise ratio and the necessary amplification available to compensate for that.

The great distance that a st 'ion can be controlled by radio relay makes it possible to locate the equipment proper not only on a high elevation but in a more central geographical location for the area of coverage. A low-powered transmitter on a high elevation always has a greater range and efficiency than a high-powered transmitter on a low elevation. This is always the case in very high frequencies and microwaves. If the dispatching point controls an antenna elevation of 100 feet total, it has a minimum radio horizon of at least 14 miles. But, if it has a mountain or hill elevation of 1600 feet 25 miles away, from that point there is a minimum radio horizon of 56 miles. At all times, the other station (that is, the mobile station) has some elevation of its own which produces a horizon of several miles. The two horizons can be added together. It is not uncommon for a mobile station to traverse areas of such elevation as to give it a horizon greater than that enjoyed by the fixed station. Because of this fact, plus additional range resulting from using better equipment, such as FM, and terrain with better ground conductivity, it is usually safe to expect a coverage of approximately twice the minimum radio horizon for the fixed station of the system.

Relay stations can be of low power and inexpensive design because they communicate with only one fixed point. This makes it desirable to use directional antennas to focus the energy in only the desired direction, which is equivalent to raising the power several times. On microwaves, where it is feasible to employ parabolic reflectors, this increases the relative power 100 to 1000 times, since signal is used only in the narrow cone where it is needed and is not wasted in other directions.

A complete system employing radio relay comprises:

1. Control point where intelligence originates or is handled. This is a low-powered two-way station having an antenna only sufficient to work to the remote station. A transmitter and receiver are required.
2. Remote point on a mountain, hilltop, or very high structure such as a bridge, water tower, or roof of a tall building. In addition to equipment such as at headquarters, the main transmitter, receiver, and antenna system are located here.

The operation is as follows. The announcer at the control point presses the microphone switch or button and energizes the transmitter. His speech leaves the antenna of his relay station at 186,000 miles per second to the mountain where the main equipment is located. There it is picked up by a relay receiver of a type such as that at the control point. This receiver energizes and modulates the main transmitter on the mountain. The mountain station antenna radiates the signal into space for reception at great distances by all mobile units as well as fixed stations tuned to that frequency. When the mobile station answers or initiates a call, it is picked up by the main receiver on the mountain, which feeds into and modulates the relay transmitter there. This is intercepted by the relay receiver at the control station and operates the loudspeaker at the control point.

In effect, there are two two-way radio stations on the mountain plus one two-way radio station at the control point. The main equipment operates usually on a lower frequency than the relay equipment. Whatever the relay receiver on the mountain picks up from the control point transmitter is retransmitted automatically over the main transmitter on the mountain. Whatever the main receiver on the mountain picks up from a mobile unit is retransmitted automatically over the relay transmitter on the mountain back to the relay receiver at the control point.

As a result, every fixed and mobile station in the system, regardless of location, has the advantage of the best radio location in the area of coverage. In selecting a mountain or very high location, it is necessary to weigh all the factors involved, particularly whether the extra range to be gained justifies the inconvenience of providing extra facilities, power line, special communications, and servicing facilities on a mountain if the point is isolated during winter months. Such stations are usually operated automatically and unattended, being visited about once a month.

8 Auxiliary Equipment for Emergencies

A mobile station can be inoperative and be replaced by another without serious disruption of service. However, the fixed station must

continue to furnish service at all times. An important system whose operations involve protection to life and property should make provision for communications in the event the normal equipment has to go off the air. For example, during the New England hurricane in September, 1939, many lives were saved by the use of the Cape Cod countywide system, which was the only communication available at the time, although it was not entirely completed. All the fixed stations in the various townships completely lost their power, but communication was maintained in various towns as follows:

1. By removing a complete mobile battery-operated unit from a car and operating it at the fixed station on storage batteries with the superior headquarters antenna. It is surprising what little difference in performance this makes, merely somewhat lower signal strength and a little less signal quality. Since the system had a surplus of coverage to begin with, no lack of range was apparent.
2. By borrowing a portable power plant (of the type discussed in Chapter Three) and operating the equipment in the normal way.
3. By tying up a mobile station at the headquarters entrance and having it act instead of the headquarters station. This had less range since its own mobile antenna was used.
4. By providing a chain of mobile relay stations spaced at intervals.
5. By having one fixed station take over the work of another station in addition to its own load. Wire telephone or mobile relay by radio between the two fixed points was then utilized.

The above examples indicate the type of auxiliary equipment that should be provided. If there is no provision for communication when a fixed station is off the air, it is difficult to check and overhaul the equipment. Equipment collects dust; tubes age and require replacement; and parts break down over a period of time. No one item of equipment should ever be indispensable. Advance thought should be given as to what to use for a jury rig, for instance, if the antenna or transmission line breaks down. A fixed station should be so designed that it will never be 100 per cent inoperative for more than a few minutes. It is permissible to continue operations at reduced efficiency, so long as the station can relay to an adjacent fixed or mobile station. At some time, advance thought on auxiliary provisions for emergencies will be repaid manyfold.

Some systems, such as the Connecticut State Police, having a great overlap of coverage and several times the number of fixed stations necessary to cover the state, handle breakdowns by having other stations take over. They have an interconnecting teletype service in addition to their radio facilities. They use radio to communicate only with mobile units and use wire teletype between the fixed stations. This is feasible

where a state has not too much geographical area and statewide teletype facilities can be provided without digging into the total budget too much. States of large size with few fixed stations in their systems will require other provisions, such as adequate-sized emergency power plants or standby radio equipment to carry on when the main facilities are out of service temporarily.

CHAPTER SIX

THE ANTENNA SYSTEM

1 General Antenna Discussion

No matter how fine and costly the equipment provided, it is all for naught if the antenna system is improperly designed. This holds true regardless of power within any practicable limit.

Two-way radio communication cannot be compared with broadcast reception at home, because the equipment provided must operate continuously and consistently in all available locations over the area to be covered. The home radio usually has a very sensitive receiver employing as many tubes as a two-way radio receiver. However, its receiving efficiency is very small because neither the antenna, transmission line, or equipment itself is designed for a specific frequency. It is relatively inefficient since it covers a wide band of frequencies, but this is overcome by its ability to pick up stations using enormous power, for example, up to 50,000 watts. Such power may be 1000 times the power used by police radio cars and a half million times the power that might be used in microwave communication on super high frequencies.

Two-way radio equipment compares most favorably with powerful broadcasting stations because everything matches. For example, the transmission line matches the transmitter; the antenna matches the transmission line; the receiver matches the transmission line and antenna. All the circuits in both the transmitter and the receiver are adjusted to produce maximum performance on only one frequency or wave length, namely, the one authorized by the licensing authority to the licensee. All the parts in the transmitter, receiver, transmission line, and antenna are selected so they will function properly on that frequency. The result is an efficiency many times greater than that of the finest home radio.

In all two-way radio communication, regardless of frequency, the antenna should be cut to the correct length for the frequency employed. It should be a quarter-wave length against ground or a half-wave length in free space. It may be multiples of that, provided it is properly matched

and terminated. It cannot be a random length and still perform efficiently, unless by rare good fortune it happened to be the correct size. In addition, for ground-wave frequencies, that is, exceeding 30,000 kilocycles, the antenna should be not only of the correct length but should be elevated as much as possible to provide maximum radio horizon and working range.

For best performance, particularly on ground-wave frequencies, the transmitting antenna and the receiving antenna should have the same polarization. For example, if the transmitting station antenna is horizontal, the receiving station antenna must be horizontal; if it is vertical, the other must be vertical also. In tests made in the field, only about 10 per cent of the range and very little signal strength was obtained when one station was using a horizontal antenna and the other a vertical one. Furthermore, this 10 per cent figure kept increasing up to the maximum 100 per cent as the antennas were moved to identical angles. A small amount of wrong polarization is unavoidable and can be tolerated: when, for instance, a car is on an incline and the headquarters station is still operating on a level terrain; when an airplane glides or climbs; or when a boat at sea rolls or pitches.

The mobile station usually influences the antenna polarization. It is more convenient for the mobile station to use a vertical antenna, such as the fishpole type; therefore, the fixed station must do likewise. Usually, the vertical type is preferable in any case at the fixed station, since it is easier to support and has less wind resistance.

Since most two-way communication must of necessity be handled on the higher frequency spectrums: very high frequency (VHF), ultra high frequency (UHF), or super high frequency (SHF), the antennas should have heights which will make possible the maximum optical and radio horizons. This requires getting the antenna as high as possible. It is immaterial how this is accomplished. The antenna can be on top of a high building, atop a tower or mast already existing or especially built for that purpose, atop a hill or mountain, or carried aloft in a balloon or airplane. The point is to get it up high and keep it there. The mobile station has certain areas to travel and cannot control its antenna elevation. It is up to the fixed station to do that. Height at either point is useful in extending the range; when both have height, maximum range can always be expected with normally operating equipment.

The ideal setup is where the transmitter and receiver are located close to the antenna, so that minimum interconnecting transmission line is necessary with consequently minimum power losses in the transmission line. When this is not feasible, make sure the transmission line between the equipment and the antenna will not detune the circuit and will not

radiate itself instead of the antenna alone performing that function. The transmission line must be so designed that it cannot be anything but a transmission line; it must not be an antenna since it is poorly located for radiating purposes. Only the antenna should perform the radiation into space, because it is ideally matched and best located for this function. The antenna radiates into unobstructed space. The transmission line cannot do so since it may be enclosed.

In the final analysis, the fixed station usually requires a mast or tower whose sole or principal purpose is to elevate the antenna. In some cases, as in the Maine State Police system, the tower or mast itself, being made of steel, serves as an antenna for medium frequency, in addition to providing height for the ultra-high-frequency antenna. Such dual duty is possible simultaneously without interaction between the two, since their frequencies (in this case 1642 kilocycles and 39,900 kilocycles) bear no harmonic relationship. In fact, in this particular system everything counts. For example, the top 15 feet of each guy wire is electrically part of the steel tower and this provides top loading or an umbrella design which gives better radiation and coverage for about 200 miles on 1642 kilocycles from a modest amount of power and has less coverage outside the state.

If the wave length employed necessitates too long a dimension for a quarter-wave or half-wave antenna, then the antenna should be made as long as possible. The shortage in length should be compensated for by loading the antenna with inductance and capacitance. This is not so efficient but is nevertheless necessary and advisable in some cases. It is particularly true where medium-frequency or low-frequency transmissions must be made from a mobile station, such as a small boat, plane, or vehicle.

The height of a tower or mast is dependent on the available land or space, on erection costs, problems, and hazards. The cost of a mast or tower need not be prohibitive. It is possible to select a type which can be erected in all or in part by the purchaser; otherwise, erection costs may exceed the mast materials. Masts described in this chapter are the guyed types, either lattice or tubular, that purchasers can erect themselves, if necessary. Masts higher than about 200 feet, particularly the self-supporting type, should be designed and erected by a steel or engineering firm.

A mast should be climbable or of a type that can be lowered to the ground on occasion.

Whenever possible, the best ground system should be provided, as it increases the range and signal strength, and even makes possible using less antenna height to cover the area. Modern broadcasting stations spend

large sums for their ground systems. For example, they may use 120 radial wires extending in all directions, evenly spaced, from the base of the tower. Each wire being a quarter-wave length long. These wires are buried below the earth's surface usually. While this is admittedly excellent so far as performance goes, it usually is too costly and inconvenient to provide; frequently, roadways, buildings, abutters, and the like, make it impossible to provide. Sufficient performance is obtained by using a location having a water level close to the surface and/or by driving several long copper-weld metal rods of lengths up to 20 feet into the ground around the base of the mast and joining them to the mast.

2 Components of an Antenna System

These components of an antenna system vary greatly with the type of station involved. The most elaborate system may include any of the following:

1. Antenna unit proper mounted on top of the mast.
2. Tower or mast to support the antenna at maximum elevation.
3. Coaxial transmission line from the equipment to the antenna.
4. Dry nitrogen gas system to maintain pressure in the coaxial transmission line so that it will always be dry and free from corrosion. An alternate provision is to use a dehydrating system and a silica gel unit to remove moisture from the air inside the coaxial line.
5. Mast or tower foundation base below frost line.
6. Anchorages or deadmen to serve as point of attachment for the guy wires.
7. Guy wires or cable to hold mast or tower erect.
8. Turnbuckles to maintain proper tension on guy wires.
9. Shackles to attach guy wires to turnbuckles or as required.
10. Insulators to prevent guy wires from forming part of the antenna system; to isolate required parts when guy wires form part of the antenna system; to divide the guy wires into different lengths so that they will not be harmonically related to the transmitting frequency. Otherwise, the guy wires absorb energy and reradiate on a harmonically related and totally undesired frequency with over-all loss in the station's efficiency.
11. Leg clevis for attaching guy wire or insulator to leg of tower.
12. Insulator clevis for connecting a series of insulators together. If necessary, seized cable may be used instead.
13. Base insulator for a tower insulated from the ground. Towers serving only as elevated supports for an antenna should always be grounded and not insulated at the base. It is better to have the antenna as high as possible but at the same time to have the ground close to the antenna. The antenna tower simulates that ground or high hill.
14. Mast lighting system as required by the Civil Aeronautics Administration so that the high tower is not a menace to aviation at night.
15. Mast painting scheme as required by the Civil Aeronautics Administration so that the tower has maximum visibility to indicate its approximate height to aircraft during daylight.

Actual photograph of a completed 20-foot section of Wincharger tower. Weight 10.1 pounds per foot of height. This section is now installed at the state police barracks at Station WSTR, Thomaston, Maine.

16. Buried radial wires or metal rods driven into the ground to form a ground system. In extreme cases, bury any available conducting metal or other conductive material at or near the mast and connect to it. Water, steam, or gas pipes are only partially effective unless all joints are bridged with jumpers to overcome the poor conductivity where an insulating compound of some sort has been used at each threaded joint. This is particularly true of the sheath of a coaxial cable using solderless connectors with rubber gaskets inside. It is advisable to use jumpers at every break or joining of two metallic lengths, unless it is definitely established that good electrical contact exists without a jumper.

3. Wincharger Type of Tower

The Wincharger tower was originally developed in only the lighter weights for use up to about 85 feet maximum height to support 6-volt to 32-volt wind generators. At the request of public agencies, the manu-

facturer redesigned the tower in a choice of types and weights suitable for two-way radio fixed stations. The instructions for erection are simple, and the purchaser can install this tower with regular personnel, if desired. The use of guy wires and its reasonable amount of "give" as well as its lattice construction provides a large margin of safety in storms of even hurricane force. The cross braces are used to climb this type of tower.

The tower must not be permitted to become rusty. This is avoidable by keeping all parts painted at all times. The principal danger thereafter is too slack or too taut guy wires. The tower must not be guyed too rigidly or it will fall if tremendous force is exerted against it. Too slack a guy wire causes a mast to sway and jerk until finally a guy wire snaps. Some slackness is desirable, and a compromise is recommended. A small amount of sway is permissible, increasing toward the top of the tower. A rigid mast holds together until it buckles or snaps. A mast having a small amount of slack, give, or even twist is more resilient; instead of buckling or snapping, it tends to appease the forces seeking to destroy it by slightly giving way from the direction that the force is being applied. The hundreds of bolts should be tight at all times with the nuts held in place by lock washers. They should be checked again shortly after installation. Thereafter, particularly if painted over, there should be little occasion to tighten them again.

4 Erecting a Wincharger Tower

There are three possible methods of erecting a Wincharger tower, all of which can be successfully handled, but the third method, which is described here in detail, is the only one recommended for masts of important height.

1. Assemble the entire tower on the ground, including guy wires, and have a crane, gin pole, or hoist from a tree or building roof take hold of the tower about 2 to 5 feet above the middle and lift it. The tower will then tilt up correctly, and it can be placed in position immediately and be bolted down. This method has been used successfully on towers up to 85 feet, and could conceivably be used for even greater height. The tower has a tendency to become bent or set if it is not protected during the lift. Such a set can then be corrected only by using guy wires at the point of the set and taking a strain on it with turnbuckles.

2. Have a platform to work from higher than two mast sections above the ground, and hoist the mast section by section, attaching one from underneath each time. This method requires more and more men to hang onto the guy wires as the mast rises. It is more dangerous, particularly if a storm should come up in the midst of the work, and though workable is not recommended.

3. The shooting gin pole method is preferable in all cases, since there is complete control of the tower at all times, and work can be stopped at any time without fear of damage to the part already erected. This method also requires a minimum amount of equipment and crew. Instructions for this method are given below:

Equipment necessary for shooting gin pole method:

(a) 30-foot gin pole, 2½-inch to 3-inch heavy wall pipe, depending on the type of tower to be erected.

(b) ¾-inch hoisting rope at least twice as long as the height of the tower being erected (preferably 20 feet longer).

(c) 2 double blocks and 2 single blocks.

(d) Wire stretcher (for taking slack out of guys).

(e) ½-inch rope 50 feet longer than height of tower, for raising gin pole.

(f) ¼-inch light rope (height of tower) as guide rope for tower section being raised.

Place the first 20-foot section in position and attach three temporary guys to the first set of anchors. Install a temporary anchor at the base of the tower, and attach a double block to it. It is possible to tie this block to a rope around the tower base. Hoisting rope must run through this, so that strain is always downward on tower.

Attach the gin pole to this tower section. Do not attach the gin pole to one leg but rather attach it to the braces in the center of one side of the tower. This makes it easier to fit the tower sections together when lowering the top section.

A long bolt at the base of the gin pole should rest on a cross brace and take all the weight. The gin pole can then be tied at the top of the tower section and again 5 or 6 feet below the top. The gin pole should extend at least 12 feet above the top of the tower. A single block should be hooked in the top of the gin pole.

To raise the next tower section, attach the pull-up rope to a cross brace 9 feet down from the top (1 foot off center). Usually the rope is wrapped around this brace and then wrapped around another brace a few feet down, for safety. Always remember that the offset ends of the tower section point downward; therefore, the pull-up rope should be attached 9 feet from the straight end of the tower section. A light ¼-inch rope should be attached to the bottom of this tower section to help in guiding it into position while being raised.

The pull-up rope should run from the tower section on the ground up through the single block on top of the gin pole and then straight downward to the double block at the base of the tower; from there to the hoist car that is to provide the pulling tower.

Slowly raise the section to the top of the tower so that it will be just even with the top of the tower. For small adjustments on raising tower, have one or more persons hang or stand on the pull-up rope, as this raises the tower section the fraction of an inch necessary for fine adjustment. Use aligning pins to align the splice holes and loosely install all splice bolts; after they are all installed, tighten securely.

This top 20-foot section can be plumbed and temporarily guyed. On the heavier towers, such as No. 101 and No. 150, this temporary guying is not necessary as the tower is sufficiently strong to proceed with hoisting on the next tower section, provided, of course, that the rope always pulls *downward* through the

pulley at the base of the tower. Never pull outward with a hoisting rope as this may cause the gin pole to bend.

Tension in Guy Wire. In adjusting the guy wires, it is very important that they have the proper tension. Being long strands of wire the contraction and expansion due to change in temperature must be taken into consideration.

It is particularly important when a tower is installed in hot weather that the guy wires not be drawn too tight, for then in extremely cold weather the guy wires will contract and impose great strain on the tower itself. The Wincharger Print gives the theoretical tension of each length guy in the various temperatures. The additional weight of insulators, and the like, will change this somewhat, but the Print does give some idea as to the tension. If a special cable tension meter is not available, use an ordinary, spring-type scale, attach it to the guy wire, and pull the desired tension, carefully marking with a stake the position of a point on the guy wire in that tension. Then the guy wire can be loosened, the scale taken out, and the guy wire tightened until the point on the guy again becomes opposite the stake.

Another method is to plumb the tower carefully through the use of a transit on all three sides. With a transit of sufficient magnifying power trained on the point of attachment of the guy with the tower leg, it can be observed when the guy is tightened sufficiently to cause a slight deflection of the leg. When this occurs, the tension is reduced to the proper point where there is no deflection of the leg or undue stress on the tower.

Guys should be periodically checked with a transit, if possible, to see that there is no deflection of the legs and that the tower is perfectly level.

Tower Base. The concrete tower base should be at least 3 feet in the ground. On towers 200 feet or under, the base can be 2 feet square at the top and 3 feet square at the bottom, and should be 7 feet tall (4 feet in the ground and 3 feet above the ground).

The reason for having the base above the ground is to prevent snow from drifting around the base insulator, causing it to short out. In areas where there is no danger of snow drifting, it is not necessary to have the base extend more than 1 or 2 feet above the ground.

On towers 200 to 300 feet tall, it is advisable to have the base 3 feet square at the top, 4 feet square at the bottom, and 7 feet tall.

5 Lighting and Painting the Tower

Radio towers, because of their height, can be both a menace and an aid to aviation. To make them predominantly an aid, the Civil Aeronautics Administration has set forth requirements for painting them to improve their visibility during daylight and for illumination to make them readily distinguishable at night.

Towers under 200 feet must be illuminated with prismatic lights at three levels: one-third of the way up, two-thirds of the way, and at the top. The number of lights at each level depends on the visibility of the tower, as it must be visible from all angles of approach. This ordinarily means having at least two lights at each level on opposite sides of the tower. Towers higher than 200 feet must have a blinking top light or must operate a coded signal. The supplier of the tower components is usually

acquainted with the latest regulations and can advise the purchaser as well as supply him with lighting fixtures. If the tower is insulated from the base and the mast is the vertical radiator, then a lighting choke must be inserted in the lighting line to prevent burning out the lamps. The reactance of the choke prevents this. Grounded towers do not require a lighting choke. Keeping the tower height to 195 feet avoids the necessity for a blinking light atop the tower, as an approved type is very costly.

To prevent burning out bulbs too frequently and to save climbing the tower to replace them, particularly in winter, special traffic-light bulbs are used with a higher voltage rating, for example, 125 or 135 volts instead of 110 or 115 volts. Cheap bulbs should not be used, as their life is too short. The cost of a good bulb designed for the purpose is small compared with the inconvenience of a trip up the mast.

The Civil Aeronautics Administration requires that radio towers be painted in accordance with a prescribed scheme. International orange and white are the colors that are used alternately, with the orange section twice as long as the white section. Each international-orange section must be one-seventh the height of the complete tower, and each white section must be half the length of the orange or one-fourteenth of the total tower height. In addition, the top and bottom sections must terminate in international orange. This color scheme has great contrast and may be seen greater distances than random painting schemes or single colors.

The paint used for the color scheme also protects the tower and therefore involves no extra expense. To prevent paint from peeling, the tower should be treated first with a liberal application of vinegar to neutralize the galvanizing on the steel mast. This may be brushed or sprayed on the mast sections before erection. Then a priming coat with aluminum paint that has exceptional covering qualities should be used before the final painting scheme is undertaken.

Thereafter, annually or as required, the international orange and white coat of paint should be renewed.

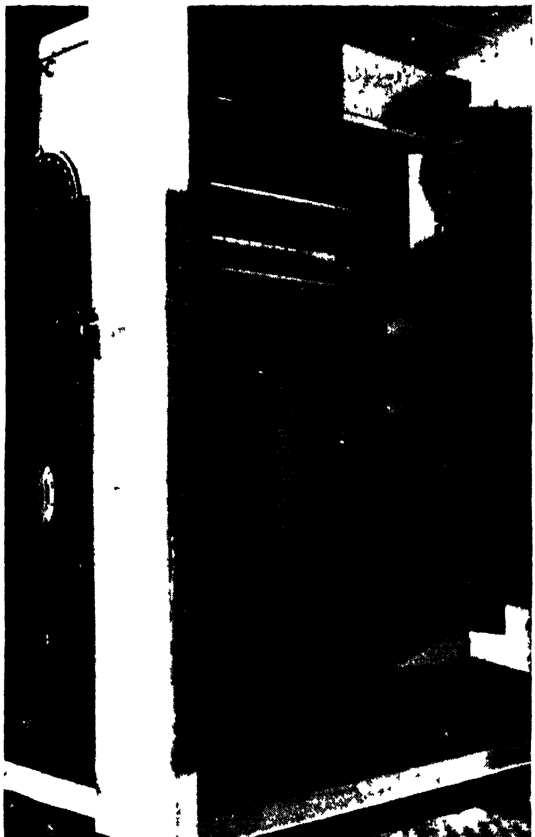
6 Transmission Line and Coaxial Cable

The purpose of the transmission line is to convey power from the transmitter, wherever it may be located, to the antenna radiator. To perform this very important function, the prime considerations are (a) to design the line for the antenna, or vice versa; (b) to design the antenna for the frequency employed.

The efficient station has a combination of design and equipment where the antenna is of such dimension, shape, and angle in relation to the earth as to correspond best to the output carrier wave of the transmitter and the areas of desired communication.

A proper antenna radiator and connecting transmission line are tremendously more important on low power than a less efficient line on high power because:

1. An antenna and transmission line usually are much cheaper than doubling the power of a transmitter.



Tuning unit used at the fixed stations of the Maine State Police. Coaxial cable enters the unit from the transmitter. A single impedance tap wire leaves coil and extends to a critical point on the Wincharger tower outdoors. Tune dial for maximum ammeter indication.

2. To make a substantial increase in range and signal strength, it would be necessary to square the power rather than merely double it. A 10-watt transmitter would have to be 100 watts rather than 20 watts. The initial and future cost for maintenance and replacements rises tremendously, whereas antenna and transmission line usually constitute a single and nonrecurring cost.

3. Due to the necessity of intermediate stages of amplification, a higher-

powered transmitter rises in cost and maintenance out of proportion to the increase in power.

4. The finest and costliest transmitter in the world is almost worthless without a good antenna and transmission line.

5. Not only must the transmission line be ideal at the time of installation, but it must remain that way permanently.

Many types of transmission lines are used. As long as any line can effect the actual transfer of energy from transmitter to antenna at great efficiency, any type can be used, but the degrees of efficiency will differ. Some types are:

1. Open single wire.
2. Two open wires.
   (a) Straight run.
   (b) Transposed along its length.
3. Twisted pair of wires.
4. Concentric or coaxial cable.

Transmission lines may be either tuned or untuned in relation to transmitter or antenna.

The coaxial cable type, sometimes called concentric cable, consists of the following:

1. Inner conductor and insulation to separate inner conductor from outer conductor.

2. Steatite beads spaced at intervals to keep inner conductor from touching and to keep inner conductor concentric or equidistant with respect to the outer conductor.

3. A solid insulation made of rubber, polystyrene compounds, or polyethylene, which is applied as a continuous coating over the inner conductor. This serves the same purpose as the beads.

4. In the case of the beads, the dielectric medium may be air or an inert gas such as dry nitrogen.

5. The outer sheath, which is the outer conductor, may be a continuous tube of copper, brass, or lead, or where flexibility is required may be a braided copper conductor. In the latter case, a jacketing material such as rubber or a synthetic resin is used.

Copper coaxial cable has the following advantages:

1. Self-shielding by virtue of its metallic sheath.

2. Outer sheath is grounded, making it safe to touch even when interior conductor is energized.

3. This line cannot radiate into space to distort the output of the antenna as open wires sometimes do. The metallic sheath prevents line radiation.

4. Inner conductor is sheltered within the weatherproof metallic sheath against, rain, snow, ice, sleet, storm, or any weather loss.

5. Can be used with gas or dehydration equipment to insure permanence of initial efficiency.

6. Can be located or concealed in transit above or below ground as may be desired.

7. Has lowest transmission-line loss known for a protected conductor under a variety of exposure conditions, particularly on the shorter waves.

8. Has a low characteristic impedance in the line, being about 72 ohms as compared to 600 ohms for open lines. In the case of solid dielectric insulation, such as polyethylene, the ratio of 3.6 produces a cable of approximately 52 ohms characteristic impedance.

9. Not critical in a frequency below microwave frequencies.

Copper coaxial cable has these disadvantages:

1. It is higher in cost. However, to have the same amount of effective power at the antenna with a less expensive type of line, it would be necessary to increase the power of the transmitter considerably.

2. Requires competent or experienced installation personnel because greater care is necessary:

   (a) To prevent shorting inner conductor to outer sheath.
   (b) To prevent disturbing the characteristic impedance because of displacement of inner conductor in relation to sheath.
   (c) To prevent cracking of steatite-insulated spacers.
   (d) To keep line gastight.
   (e) To safeguard against uncoupling of sheath or inner conductor sections at any point in its entire length.
   (f) Special fittings needed in case of larger lines to connect short lengths and to change direction of run.

3. Condensation problems if gas or dehydrated air not used. Condensation of moisture on beads results in low-resistance paths which cause increased loss of power. When coupled with moisture on the surface of the conductors, it results in an increase of capacity in the line as well as a concurrent change in impedance. In a matched line system this is dangerous because it results in increased reflection loss and increased standing-wave voltage ratio, with increased susceptibility to arc over. This is attributed to a dielectric constant of 80 for water as against 1 for air. This tends to increase capacity as would any other high-constant dielectric used in a condenser.

The power-handling capabilities of copper coaxial cable depend on:

1. Frequency or wave length employed. The higher the frequency or, inversely, the lower the wave length, the less power it can safely handle. The same would be true to an even more marked extent for any other type of transmission line.

2. Dimensions of the sheath and its component parts. The larger the proportions, the more power it can safely handle without flashing over from inner conductor to the grounded sheath.

3. Insulated spacers between inner conductor and outer sheath as regards:

   (a) Their number in a given length. The more used increases the mechanical support, which is favorable, but also increases the loss, since no insulator is perfect, and that is unfavorable. A compromise is necessary.
   (b) Their size. The greater their radius or leakage path, the lower the loss will be and the higher the breakdown voltage.
   (c) Their composition. The greater its ability to prevent the flow of electricity within itself, the lower the loss will be.

The efficiency of copper coaxial cable depends on:

1. Length of the line employed. The larger the line dimensions are, the farther the line can be extended without excessive loss. A 3/8-inch line might lose 45 per cent of its power in a distance of 400 running feet, while a 7/8-inch line would only lose 14 per cent in that distance.

2. Attenuation rate. The loss in the cable or its attenuation or efficiency varies as the square root of the ratio of the frequency. Example. 3/8-inch line at 1 mogacycle has a decibel loss of .09 db. per hundred feet. At 25 megacycles it would be .09 times the square root of 25 divided by 1. Or 5 times .09 which would be .45 db.

3. Optimum ratio. The ratio between the dimension of the inside diameter of the sheath to the outside diameter of the inner conductor. For a given size of coaxial, minimum attenuation or maximum efficiency in the line is obtained when the optimum ratio is 3.6 to give a characteristic impedance of approximately 76 ohms; 3.6 ratio gives minimum attenuation.

   (a) If ratio is less: The inner conductor is too large for the sheath size to maintain 3.6 ratio. The power or I^2R loss (current squared times resistance) increases, even though greater current can pass through the larger inner conductor.
   (b) If ratio is more; The inner conductor is too small for sheath size to remain at 3.6 ratio. The increased ohmic resistance reduces the current and again increases the I^2R loss. At frequencies above approximately 400 megacycles, the loss contributed by the dielectric becomes increasingly important and exceeds the copper losses.

4. Medium within the sheath.

   (a) Atmospheric pressure.
   (b) Increased pressure such as that afforded by gas or dehydrated air under pressure.

5. Terminating ends at interior and exterior ends of a line.

   (a) Type of insulation used.
   (b) Leakage path of same.
   (c) Weather conditions.
   (d) Power losses due to deposits on insulation affecting its insulating qualities.

6. Humidity within the line, resulting in condensation of moisture on insulators, which changes the characteristics of the line.

Gas and gas fittings are used:

1. To prevent formation of moisture in the line caused by condensation variations in temperature inside and outside the coaxial cable. Also to take care of moisture which might work into the line at connections of sections or line terminations.

2. To raise breakdown voltage of line, thereby enabling it to handle more power without flashing over.

DATA OF MISCELLANEOUS MANUFACTURERS OF COAXIAL CABLE FOR VARIOUS TYPES

Sheath	Inner Conductor	Insulation	Bending Radius	Characteristic Impedance	Attenuation Each 100 Feet	Power Rating	Usual Maximum Length Continuous
¼-inch O.D. soft-drawn copper tubing	No. 16 copper wire	Spun pyrex spirally wound	3 inches	72 ohms	19.7% .95 db @ 30 mc.	Low power	1000 ft.
⅜-inch O.D. soft-drawn copper tubing	No. 12 copper wire	Ultra steatite-bead spaced 2 inches	6 to 8 inches	75 ohms	10.9% .5 db. @ 30 mc. 2.% .09 db. @ 1 mc.	500 watts @ 30 mc. 1000 w. @ 1 mc.	1000 ft.
⅞-inch O.D. hard-drawn copper tube	¼-inch O.D. copper tube	Ultra steatite-bead spaced 6 inches	None	68 ohms to 70 ohms	3.5% .154 db. @ 30 mc. .5% .028 db. @ 1 mc.	3 kw. @ 30 mc. mc. 15 kw. @ 1 mc.	20 ft. sections

MANUFACTURERS' DATA OF OTHER TYPES OF CABLE
Loss in watts per thousand watts power for each 100 feet in length

Wave Length Meters	Wave Length Frequency	Shielded Ignition Cable	Best Twisted Pair	Best Rubber Coaxial	Amphenol Coaxial (Braided Sheath)	Amphenol Coaxial (Solid Copper Sheath)
2½	120 mc.	920	800	700	320	210
5	60 mc.	800	645	563	249	162
10	30 mc.	637	463	411	186	121
20	15 mc.	460	324	308	133	88
40	7½ mc.	324	206	206	110	65
80	3¾ mc.	206	133	135	60	49
160	1⅞ mc.	143	88	92	45	39

The gas mediums available for the lines are:

1. Dry nitrogen, oil-pumped, free from moisture. It has the following advantages for air-type coaxial cable: inert, economical, available; not inflammable, poisonous, or corrosive; does not liquefy; minimizes deposition of copper on spacer beads by reducing arcing between inner conductor and sheath conductor; makes possible curing as well as preventing wet lines merely by siphoning or bleeding gas through the line or by using a dehydrator.
2. Dehydrated air using silica gel cartridge that is very porous and absorbs many times its volume as the pumped air circulates through it and the moisture is removed in transit through same.
3. Any inert nonconducting medium.

7 Tubular Mast

The tubular mast is a patented type available in a choice of heights up to 200 feet. It is designed for quick erection. This type of mast is unclimbable or less easy to climb, except where special provisions are made in the case of the larger types. The smaller types are fairly simple to lower for servicing.

8 Antenna and Range

While an unobstructed line of sight is very desirable between the transmitting point and the receiving point, it is not absolutely essential. Signals can be refracted or reflected, so that they tend to spill over beyond the horizon as does light. However, the total range is much better if the line-of-sight cutoff is not too close to the antenna.

Illustrated here is a test conducted by the General Electric Company. Successful communication was maintained between a 30-watt FM mobile transmitter and a 250-watt headquarters transmitter approximately 90 miles apart under unfavorable line-of-sight conditions. The mountain-to-mountain reflection or wave-guide effect was believed to have contributed to the performance.

Car-to-car communication imposes the worst conditions because of limited output power and two relatively inefficient antenna systems at close-to-ground levels. However, substantial ranges are being regularly obtained. Most municipal systems can communicate communitywide car to car, since their air-line distances are not over 10 miles. In rural areas, ranges up to 50 miles between cars are not uncommon regardless of horizon and terrain conditions. However, very congested areas like the heart of a business district in a large city where the car is traveling in a canyon surrounding by an unbroken row of skyscrapers have limited range.

The General Electric Company, in its literature, claims ranges of 15 to 22 blocks in the worst skyscraper area of New York City; 5 to 7 miles

between park and residential areas; and 3 to 4 miles between park and business areas in Philadelphia; 1 to 3 miles in the downtown business area, and 6 to 10 miles from a hill overlooking the Potomac River into a rural area in Washington, D.C.

It is impossible to give an arbitrary set of figures as to how far one station can communicate with another. It depends on many factors, such as power, antenna efficiency, transmission-line efficiency, ground conductivity, physical obstructions, directional characteristics of the antenna and vehicle. As a rule, there is never less than 5 miles range car to car with a possible maximum of 50 miles. Headquarters to car is never less than 10 miles even with a low-elevation antenna with a maximum range of 50 miles or more. The larger figure in each case depends on at least one car being in a good area for elevation, ground conductivity, or unobstructed horizon. From the hillside highway climbing Mount Cadillac, near Bar Harbor, Maine, there is no trouble communicating with Thomaston, Maine, some 60 miles away, regardless of power or whether AM or FM on 39,900 kilocycles. It is not necessary to be more than part way up that 1600-foot mountain to do this.

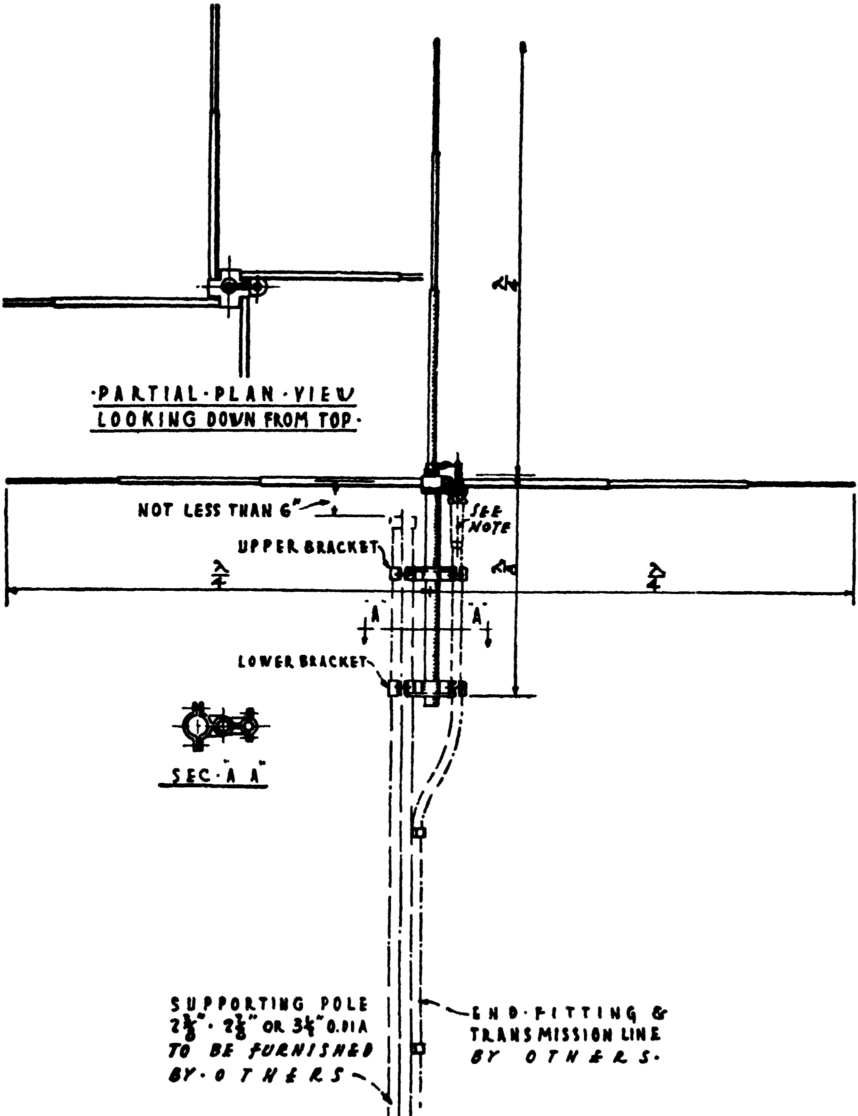
General Electric Company estimates that doubling the effective height of a station antenna above the effective ground plane is roughly equivalent to multiplying the transmitter power by four. For that reason, remote control equipment to obtain strategic radio heights for the headquarters transmitter-receiver is frequently desirable, increasing the range rather than the signal strength, although both are realized in practice.

9 Coaxial Radial Antenna

For very high frequencies, early fixed stations used the J-type antenna. This did not function uniformly in all directions and, when first installed as the best available for the Cape Cod radio system in 1937, had actual dead or highly attenuated areas with respect to the headquarters station operating in conjunction with mobile units.

The coaxial type of antenna, used for the Link and General Electric equipment described in this chapter, was a great improvement. This type gave a greater pattern uniformity, so that coverage could be maintained more closely to the maximum in all directions.

A further improvement was noted when comparative tests were made between the coaxial antenna and the coaxial radial antenna (RCA Model M17823A). The latter differs from the other types because it uses four quarter-wave horizontal ground rods in addition to the quarter-wave vertical section. The purpose of these rods is to prevent high radio-frequency fields from the antenna from inducing energy into the transmission-line sheath with the consequent flow of current on the outside of



V.H.F. antenna MI 7823 A. (Courtesy RCA Manufacturing Co. Camden, New Jersey.)

such a concentric feed line. It has been determined that without these rods power is radiated at various odd angles and wasted by upward radiation, as well as by distortion of the horizontal radiation pattern.

Another improvement is that the vertical section is grounded, thereby affording some protection from lightning and acting as a static drain

when the antenna is used for reception purposes. Whereas, in the conventional coaxial type the vertical section leads directly to the inner conductor inside the station to conduct lightning and static charges. As supplied by the manufacturer, the coaxial radial antenna comes cut for the correct frequency and clamps onto a pipe support atop the tower. The inner conductor connects to the base of the quarter-wave vertical section as shown.

For very high frequency and for medium frequency, the same antenna mast is frequently used by organizations having too much coverage for an individual station on ground waves alone. They then use very-high-frequency ground-wave communication as far as they can and medium frequency one way for the remainder. Or they may use medium frequency from headquarters and very high frequency from car back to headquarters. Or they may transmit simultaneously on both frequencies: for local cars on very high frequency, and for cars hundreds of miles away on medium frequency. It is also useful for fixed-station-to-fixed-station relaying to remote cars.

When the same antenna mast is employed, a grounded or ungrounded tower acts as the vertical radiator on medium frequencies. The coaxial line and lighting conduit also forms part of the antenna system. The very-high-frequency antenna atop the tower transmits and receives on ultra high frequency either simultaneously or independently of the medium-frequency component. There is no interaction between the two. To assure that this will always be the case, the very high frequency employed should not be harmonically related to the medium frequency; that is, the medium-frequency figure should not evenly divide into the very-high-frequency figure.

In addition to methods illustrated here, a different but very satisfactory method was devised for the Maine State Police. There the medium-frequency transmitter feeds through a ⅞-inch coaxial cable to a tuning unit in the building as close as possible to the mast. Then a single antenna lead in wire goes through space and about 42 feet from the ground taps on a 205-foot tower for best performance as determined by field-strength readings. It is not always 42 feet, because at some stations the run to the mast is more horizontal than vertical when the building is farther away from the tower. In that case, it becomes necessary to shift the tap and, if necessary, to move the tuning unit outdoors in its own house. The angle that the wire takes from the tuning unit to the tower seems to be very important.

For very-high-frequency operation in this case, the coaxial cable runs from equipment inside the building all the way to the top of the mast. The coaxial line, if permitted to run in midair from the building to the

tower for the very-high-frequency component, may adversely affect the medium-frequency antenna system. It is therefore run underground or close to the ground. In Maine it was unsafe to run the cable underground, due to wet ground and frost heaves, so it was run in a wooden conduit about two feet above the ground and was grounded at frequent intervals. This was satisfactory.

It is preferable to use a grounded tower wherever possible, since it can function on a lower frequency for a given mast height, and because it avoids the necessity of a lighting choke for the mast lighting system. Otherwise, the system would light up during transmission and burn out prematurely in the case of a powerful station. Also, a grounded mast is preferable for very-high-frequency operation since it brings the ground up to the very-high-frequency antenna without obstructing the horizon.

Medium-frequency antennas for mobile applications are available with center, top, or base loading. In effect, the loading is done externally rather than internally within the equipment. The performance is superior and permits mobile stations to get some radiation on the lower frequencies where, otherwise, they might get little or none.

CHAPTER SEVEN

AMPLITUDE MODULATION EQUIPMENT

1 AM System

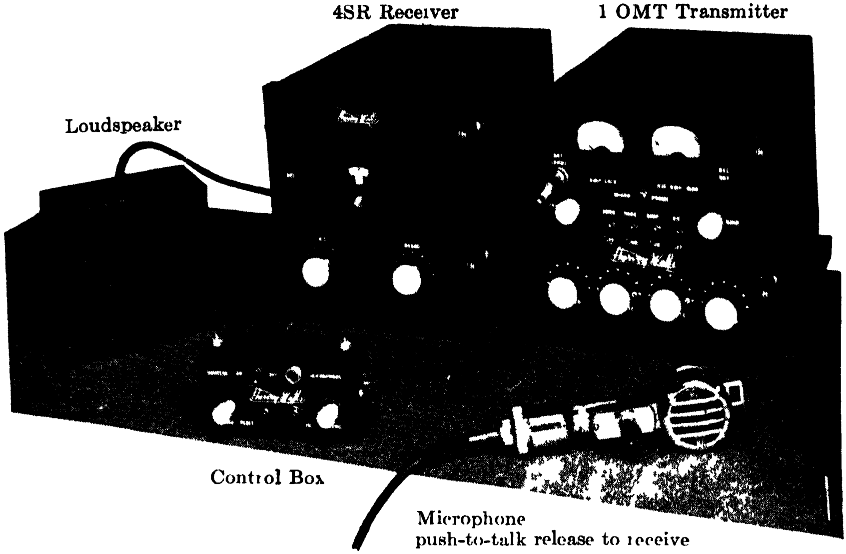
The constructional, wiring circuit, installational, and adjustment details of an actual two-way mobile radio station employing amplitude modulation described in this chapter, are based on the Harvey-Wells Model MT/AM-10 transmitter and SR4 receiver constructed by the police radio project of the National Youth Administration for the Maine State Police.

2 Transmitter Design

Instead of rigid fixed inductance coils, this equipment has removable coil forms which plug into the equivalent of tube sockets. This permits making the same equipment suitable for a choice of radically different frequencies. Tests have been made using 10 watts power on frequencies as low as 1642 kilocycles and as high as 60,000 kilocycles. By providing 6 volts direct current or replacing the power supply with an AC power supply, the same equipment is used for low-powered small-community headquarters stations or as a standby for a larger-sized fixed station transmitter.

Frequency Control. The transmitter operates either crystal control or electron coupled. For Maine on 39,900 kilocycles, the crystal is cut for one-fourth the frequency or 9975 kilocycles. The frequency is doubled in the oscillator stage and once again in the amplifier stage. By exchanging the oscillator coil and substituting a condenser plug for the quartz crystal, the equipment operates with an electron-coupled oscillator which can be tuned to any desired frequency that part components permit. Only the coils need to be changed for various frequency ranges. The condensers can remain unchanged, unless different LC ratios are desired.

Tuning Provisions. All equipment has provision for connecting meters in the circuits to obtain optimum performance. While it is customary not



Units and accessories of mobile amplitude modulated equipment (Courtesy Harvey Wells.)

to provide meters for each mobile unit, for reasons of economy or maintenance control, this equipment carries its own indicating and tuning facilities. Such provisions were considered desirable because of the application. The cars operate hundreds of miles from a regular servicing depot or regular maintenance technician during detached service. During emergencies, a qualified patrolman, amateur, or service man anywhere can check the equipment with such meters and controls. The circuit is a standard MOPA (master oscillator-power amplifier) equipment, well known to experienced radio technicians.

Servicing Ease. All parts for broadcast receivers are standard and are usually carried in stock by local radio dealers. The equipment is quickly detachable and removable from the cabinet, so that repairs can be made conveniently in a building or under shelter rather than working in cramped rear-trunk space outside in the dark or in unfavorable weather. The equipment is designed to permit exchanging units for routine overhaul or to remove completely and reinstall when new cars are purchased, or when a car engaged in more important duties requires a replacement set from a car in less important duty. The transmitter is independent of the receiver, so that if one unit is inoperative the other still functions to permit transmission or reception as the case may be.

3 Associated Receiving Equipment

For better-quality local reception, the superheterodyne type of receiver is usually employed. This has become increasingly so, as trans-

mitters adopted crystal control and acquired good frequency stability; also, as greater attention was given to noise and interference suppression from various sources. However, the illustrations in this chapter are based on the superregenerative type of receiver. Such equipment is permissible under the following conditions:

1. Where the steady battery-power drain must be reduced. A saving of 2 to 4 amperes results from using the superregenerative receiver as compared with the superheterodyne type.
2. Where maximum range is far more important than signal quality.
3. Where size, cost, weight, and simplicity are of utmost importance.
4. Where very poor signal-to-noise ratios exist for superheterodyne equipment.
5. Where a system is undergoing a period of transition, and it is desired to keep the investment small but still have communication until new developments become available.
6. Where interference squeals from several regenerative receivers present no annoyance, such as in rural areas with units several miles apart.
7. Where transmitters drift in frequency due to great temperature changes or long periods between routine tune-ups. In northern Maine, temperatures fluctuate from 80 degrees above to 50 degrees below zero. A selective superheterodyne might be too sharp in tuning characteristics to hang onto the transmitting signal. The superregenerative receiver can do so, since it tunes up to fifty times as broad in terms of kilocycles. In isolated areas where other stations do not interfere on the adjacent frequencies, such broad reception can be tolerated.

4 Parts for the 10-MT

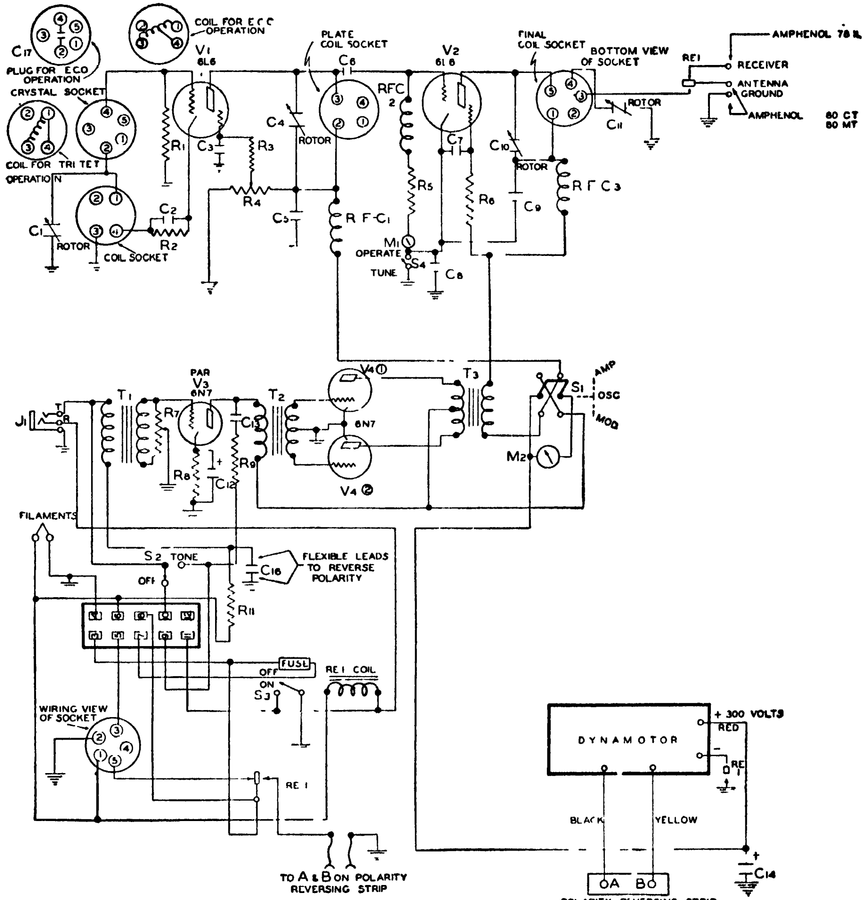
Standard parts are used that can be cheaply and universally obtained or substituted. Usually, basic parts used by radio service men in repairing standard broadcast receivers are suitable for mobile two-way radio equipment. It is necessary only to select the better grade of parts and make sure that each part is of a size that has a good safety factor. Parts that are rated at 200 per cent greater breakdown voltage and of a size that has greater wattage rating than encountered in the circuit are satisfactory. Parts with too low a wattage rating dissipate heat and develop trouble. Too large a safety factor makes the parts unduly large, expensive, and difficult to procure in remote localities.

A single antenna serves both transmitter and receiver by means of a transfer relay. This relay has an extra set of contacts to cut off the high voltage immediately from the transmitter when transmission ceases and before the dynamotor has coasted to a stop.

Fuses are provided in the event that the battery has to provide more than normal power, due to shorted parts or a stuck armature in the dynamotor.

Wherever a wire comes through a hole in metal, a rubber grommet is used to prevent chafing. Shielded wires are used in the circuit handling the voice.

Transmitter and receiver units have separate power supply sources to develop the high voltages required during actual communication. This reduces storage-battery drain by the use of a small, inexpensive, and readily replaceable vibrator for the receiver which is in constant operation. For the transmitter which requires greater power input, it is good



Circuit diagram of the transmitter.

practice to provide a special dynamotor or miniature DC high-voltage generator for the purpose. This has the added advantage that if the power source for one unit fails, the other still functions. In an emergency it is better only to transmit or only to receive than not to be able to do either. The vibrator costs only about one-tenth as much as a dynamotor and can be plugged in or removed as readily as a tube. The vibrator in con-

junction with the receiver is in operation from 50 to 200 times as much as the dynamotor in conjunction with the transmitter. This equipment draws from the car storage battery at 6 volts the following amperages:

	Amperes
To light the transmitter tubes	2
To light the receiver tubes	2
To operate the vibrator in receiver during reception	4
Total	8
When microphone button is depressed and dynamotor functions add	14
Total during transmission	22

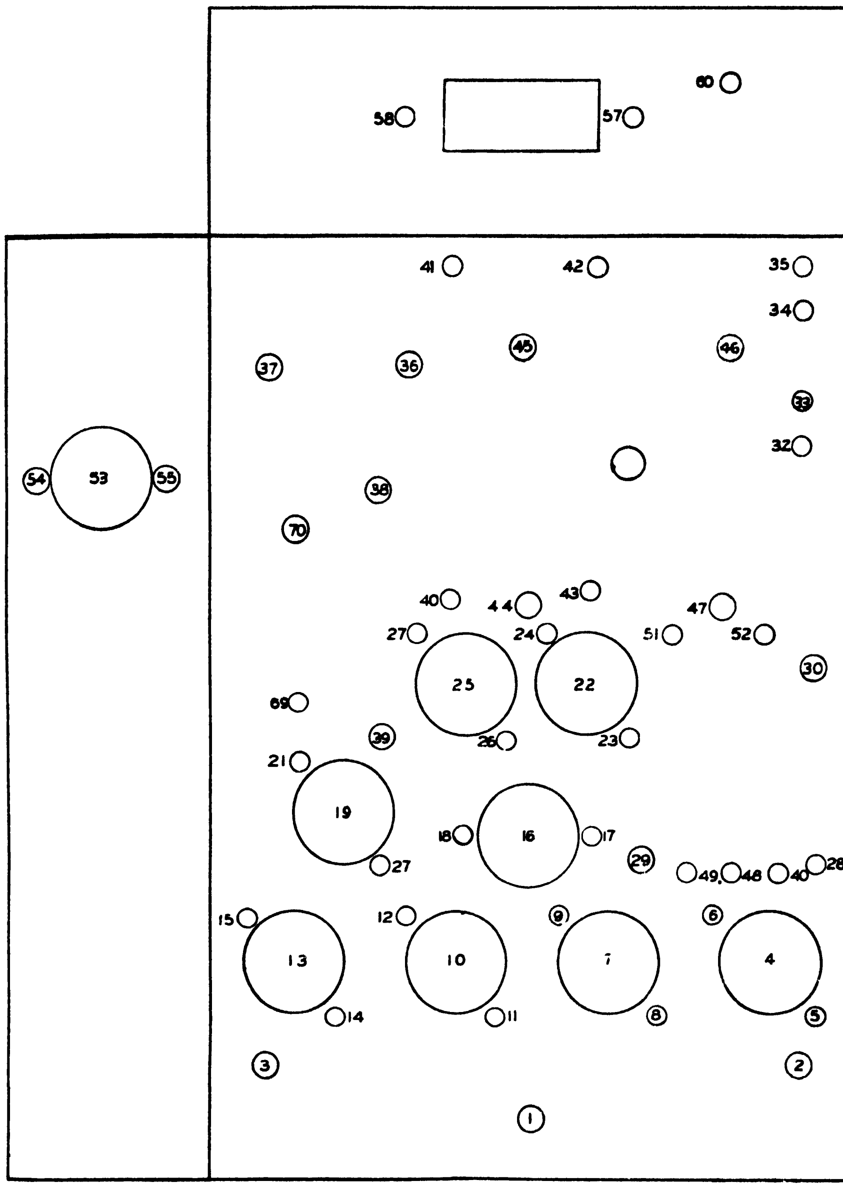
The parts are designed on that basis with a good safety margin in voltage and wattage rating.

Function	Rating
C1—Oscillator cathode tuning condenser	100 mmf. 500 v. variable air
C2—Oscillator cathode by-pass condenser	.01 mf. 500 v. mica
C3—Oscillator screen by-pass condenser	.002 mf. 500 v. mica
C4—Oscillator plate tuning condenser	50 mmf. 500 v. variable air
C5—Oscillator plate by-pass condenser	.002 mf. 500 v. mica
C6—Amplifier grid feeder condenser	50 mmf. 500 v. mica
C7—Amplifier screen by-pass condenser	.002 mf. 500 v. mica
C8—Amplifier cathode by-pass condenser	.01 mf. 500 v. mica
C9—Amplifier plate by-pass condenser	.002 mf. 800 v. mica
C10—Amplifier plate tuning condenser	50 mmf. 500 v. variable air
C11—Antenna tuning condenser	50 mmf. 500 v. variable air
C12—Amplifier cathode by-pass condenser	10 mf. 25 v. electrolytic
C13 Tone condenser	.1 mf. 400 v. paper
C14—Dynamotor filter	8 mf. 450 v. electrolytic
C15—Relay contact condenser (optional only)	(May be omitted) .1 mf. 400 v. paper
C16—Microphone filter condenser	10 mfd. 25 v. elec.
C17—Electron coupling condenser	.0001 mf. 500 v. mica
R1—Oscillator grid resistor	100,000 ohm ½ w.
R2—Oscillator cathode resistor	300 ohm 1½ w.
R3—Oscillator screen resistor	25,000 ohm 1½ w.
R4—Excitation control	50,000 ohm 2 w.
R5—Amplifier grid resistor	20,000 ohm 1½ w.
R6—Amplifier grid resistor	10,000 ohm 1½ w.
R7—Gain control	500,000 ohm 1 w.
R8—Speech amplifier cathode	1000 ohm ½ w.
R9—Tone resistor	4700 ohm ½ w.
R10—Speaker volume control	100,000 ohm 1 w.
R11—Microphone filter	200 ohm ½ w.

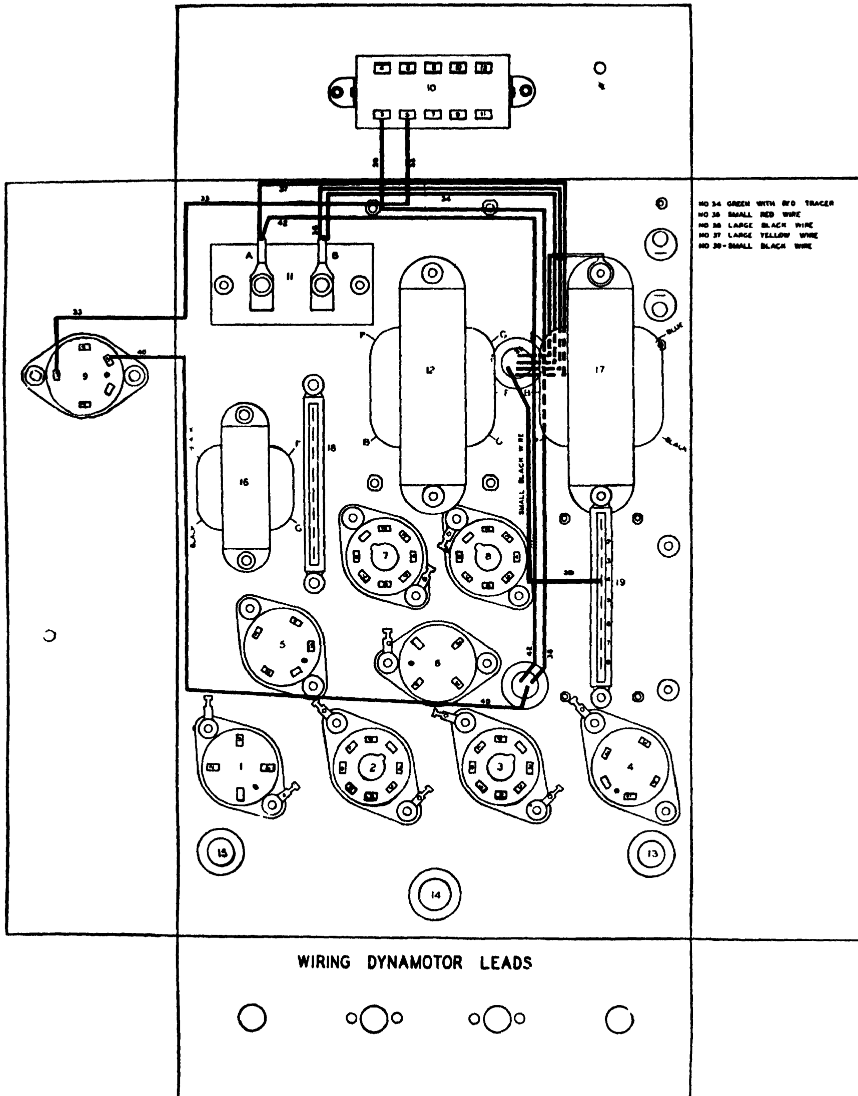
5 Constructional Procedure

In constructing the equipment, attention must be given to the following:

1. Physical considerations, which include the size of parts and the over-all dimensions or weight.



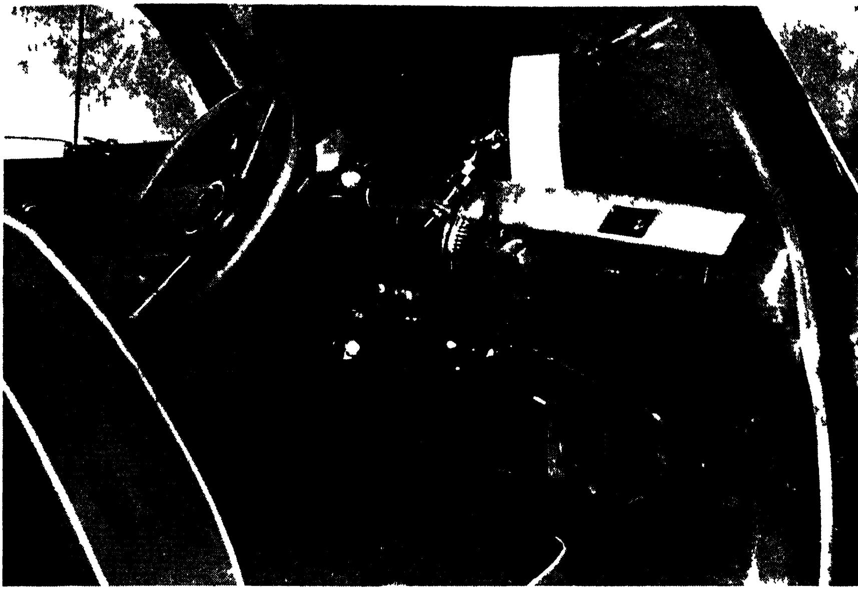
Sheet-metal chassis for 10-MT transmitter with all holes prepared.



Appearance of chassis bottom of 10-MT transmitter after dynamotor wiring is completed.

2. Mounting considerations, which include the accessibility of parts for wiring in, and also for adjustment, removal, replacing, checking, or repair of parts after they are once mounted or built in. Parts should be accessible to pliers, wrench, or soldering iron.

3. Mechanical considerations, which include checking parts so that they will not get loose under vibration or normal service conditions or become otherwise damaged and inoperative.



Equipment controls in driver's compartment. (Courtesy Maine State Police.)

4. Electrical considerations, which include seeing that connections will not become electrically intermittent or variable. Each connection should make good contact by twisting or securing the wire on the lug so that it holds even if unsoldered; also, by holding the wire to the lug with actual solder and not by rosin in whole or in part.

The accompanying illustrations will help to visualize the following breakdown of construction for the 10-MT transmitter:

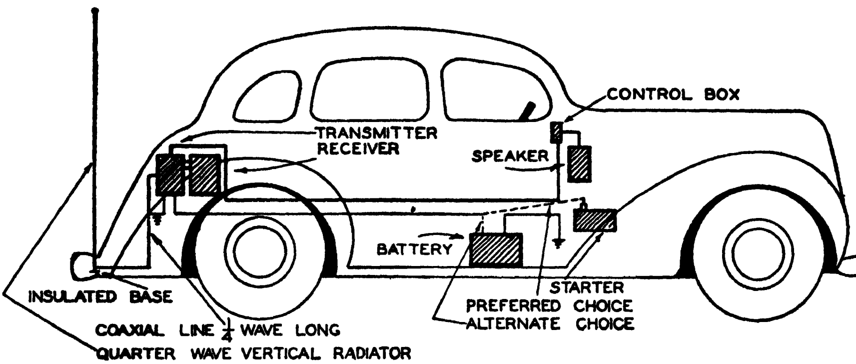
1. Chassis assembly.
2. Wiring in the filament connections to all tubes.
3. Wiring in the dynamotor circuits.
4. Wiring in all grounded and bonded circuit connections.
5. Front panel assembly.
6. Installing the mobile antenna.
7. Transmitter installation.
8. Tuning procedure.
9. Operating the completed installation.

6 Making the Mobile Installation

In the case of a moving vehicle such as a police car, the following units must be installed:

1. Transmitter unit in rear trunk.
2. Receiver unit in rear trunk.
3. Loudspeaker behind grill in driver's compartment.

4. Antenna on rear bumper. A higher location is optional at the expense of marring the body.
5. Remote control box on dash in driver's compartment.
6. Microphone convenient to driver in front compartment.



Block diagram showing typical two-way remote control police radio mobile installation. The transmitter and receiver units are mounted in the rear compartment of the car. The remote control unit and the speaker are mounted in the front or the driver's compartment. The power supply for both units is self-contained in the respective cabinets. The large cable running from the transmitter to the remote control point provides the necessary circuits for control of both units. The units are tied together with a small cable that provides for all necessary switching and control of operation between units. Note: whenever possible live battery lead should be connected to live terminal of starter, rather than battery

7 Operating the Equipment

Starting from completely turned-off condition:

1. Turn the toggle switch on the control unit from OFF to ON. This lights all the tubes in the receiver and in the transmitter. It also starts the receiver vibrator power supply. The green light comes on in the control unit. The receiver is in full operation after about thirty seconds. The transmitter tubes warm up at the same time ready to allow transmission when the microphone button is depressed. This is the standby position.
2. To transmit, depress the microphone button located on the switch handle, and talk. When the button is depressed, the red light comes on in the control unit. The dynamotor starts up and the antenna is transferred automatically from the receiver to the transmitter as long as the button is depressed.
3. To return to the receiving standby condition and to cease transmission of either voice or carrier on the air, merely release the microphone button.
4. To shut off the equipment entirely, merely turn the toggle switch on the control unit from ON to OFF.

The following accessories or conveniences are provided:

1. Volume control. This control reduces the volume to loudspeaker from receiver to any level below maximum. Remember to turn it up sufficiently after reducing it.

2. Tone control. By pressing the tone button on the control unit, with the microphone button depressed during transmission, a characteristic tone is sent out on the air. It can be used to attract attention by telegraph dots and dashes, or at the limit of the communication range can serve as a signal back to the transmitting point that a transmission has been received. The latter use is of value when voice is too weak for recognition.

CHAPTER EIGHT

FREQUENCY MODULATION EQUIPMENT

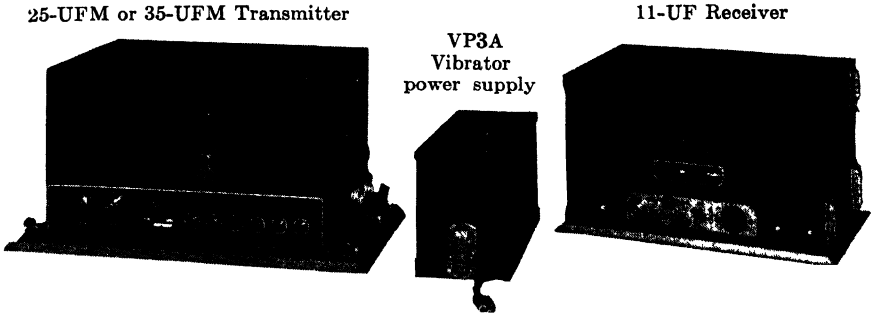
1 Discussion

The modern frequency modulation equipment, designed for 30–40 megacycle operation, described in this chapter, is based on the Link type 25-UFM transmitter and 11-UF receiver, similar to that constructed for South Portland and Bangor, Maine, by the police radio project of the National Youth Administration. It is comparable with the equipment of Motorola, General Electric, and others, previously described. Identical or similar equipment is widely used today by state, county, and city police, as well as by other agencies throughout the United States and several foreign countries.

This equipment was first used by the Connecticut State Police in 1940 and became the first two-way FM radio system in the United States. It utilizes the FM developments of Major Edwin H. Armstrong. It was first designed by Dr. Daniel C. Noble, now chief engineer of Motorola, and first manufactured by the firm of F. M. Link.

This equipment has demonstrated its ability consistently to outperform comparable amplitude modulation equipment both in quality and in range for a given power consumption and frequency. It therefore has become the principal if not sole type of equipment used in new installations where sufficient frequency channel space can be spared and operations are conducted on 30 to 40 megacycles.

Although the equipment described is the basis for the modern two-way FM set, it has counterparts with the same or with other manufacturers. When provided with a larger dynamotor capable of applying higher voltage to the anode of the final amplifier, it may be called the 35-UFM, indicating that it has 35 watts output power instead of 25 watts. If, in addition to a larger dynamotor, two tubes are used in tandem for the final amplifier stage, it may be rated at 50 or 60 watts. Theoretically,



Units of Link type FMTR equipment (Courtesy F. M. Link)

there is no limit to the rating or loading of a set until finally it ends up in "smoke."

The purchaser should determine whether an equipment has a higher than usual power output on the basis of larger components or on the basis of driving the equipment harder.

Fixed station equipment is identical, except that it is ordinarily designed to function from regular lighting current (115 volts 60 cycles AC). Instead of a dynamotor in the transmitter or a vibrator in the receiver, it employs a rectifier, involving one or more additional tubes. Such equipment is then known as 25-UFS instead of 25-UFM.

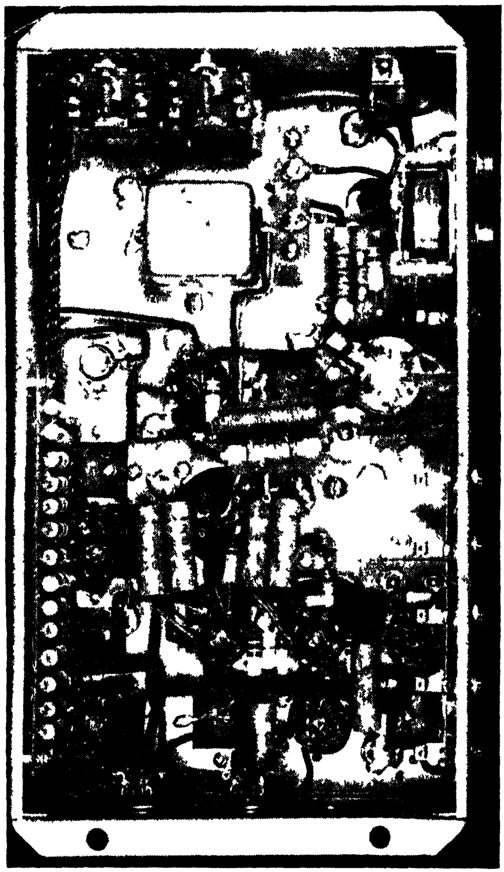
Some inconsistency may appear to exist by the use of UFM (ultra high frequency FM) instead of VFM (very high frequency). Equipment designed prior to March, 1943, referred to frequencies between 30 and 300 megacycles as very high frequencies. At that time, as previously stated, the Federal Communications Commission named this band very high frequencies. Ultra high frequencies now designate frequencies between 300 and 3000 megacycles.

2 Transmitter Design

The FMTR frequency modulation mobile equipment is a complete assembly designed for mobile two-way communication on the 30–40 megacycle very high-frequency band. It consists of the 25-UFM 25-watt mobile FM transmitter, 11-UF mobile FM receiver, VPA-3A synchronous vibrator-type receiver power supply, and all accessories for accomplishing an operating two-way communication system in a mobile unit. The equipment is designed normally to derive all of its primary energy from the 6-volt 3-cell lead storage battery available in such units. Models available on special order are 12-volt and 24-volt.

The 25-UFM (Ed. 2) transmitter is a 25-watt (nominal output) frequency-modulated unit designed especially for mobile use. Its salient characteristics are as follows:

Power output: 25 watts (nominal).
Frequency range: 30–40 megacycles.
Type of emission: Frequency modulated.
Frequency deviation: Plus and minus 15 kilocycles.
Audio range: 300-3000 cycles with high-frequency pre-emphasis.
Weight: 29 pounds.

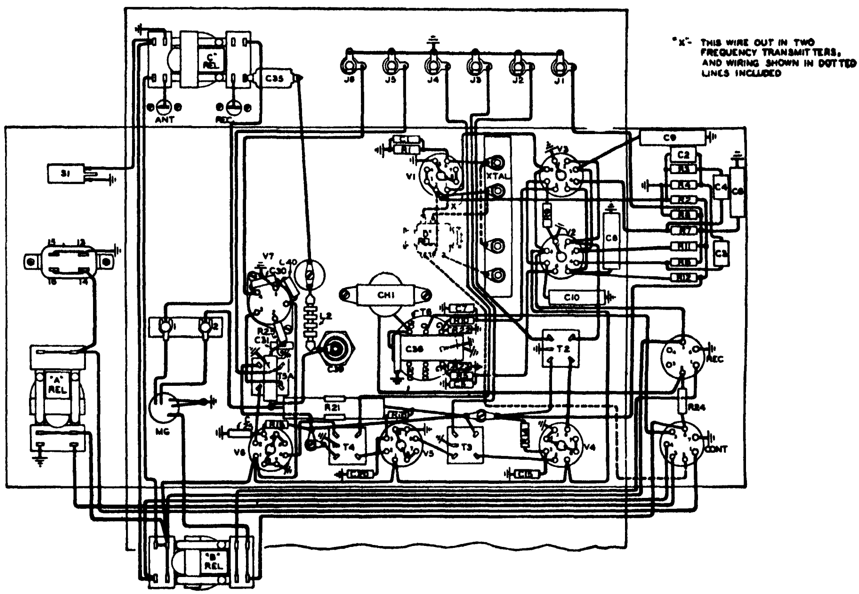


Subchassis view of 25-UFM (original model) now in use by Police, Fire, and Public Works Departments of South Portland, Maine.

Over-all size: 9 by 17 by $8\frac{1}{4}$ inches high.
Tube types: (3) 7C7; (2) 7A8; (1) 7C5; (1) 807.
Power supply: Self-contained dynamotor.
Power input: 6.0 v. @ 2.25 a. Standby—13.5 watts. 6.0 v. @ 23 a. Transmitting—138 watts.
Mounting: Snubbing-type rubber shock mountings.
Output impedance: Any—usually fed into concentric line.

Control: Remote by self-contained relays—provisions for co-ordinated receiver control.

The Type 25-UFM frequency-modulated transmitter utilizes the phase-shift method of obtaining the desired deviation. This permits both direct crystal control of the carrier frequency and a simple circuit design with no critical tuning adjustments. It is designed for a maximum frequency deviation of plus and minus 15 kilocycles in its operating range of 30 to 40 megacycles. A carrier power considerably in excess of 25 watts is available under normal operating conditions in mobile service.



Layout diagram of 25-UFM transmitter.

The transmitter is entirely self-contained and utilizes a dynamotor to convert the 6-volt input to high voltage for plate supply of the tubes. Seven tubes are included on the chassis, six of which are of the low-drain receiving type. The tube types and their uses are as follows:

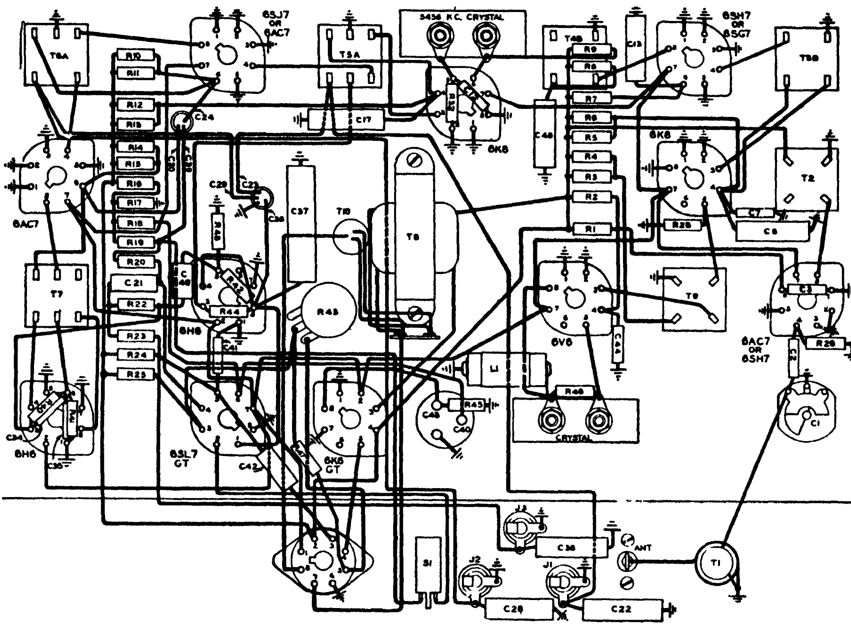
1 Type 7C7	Crystal oscillator.
2 Type 7A8	Balanced modulators.
1 Type 7C7	Frequency quadrupler (first).
1 Type 7C7	Frequency quadrupler (second).
1 Type 7C5	Frequency doubler.
1 Type 807	Final or power amplifier (PA).

From the above list it is seen that the crystal frequency is multiplied 32 times in order to obtain the final operating frequency. Metering jacks are provided in the grid circuit of each stage for convenience in making

adjustments. All tuning adjustments are straightforward and small errors in making them will not affect the output frequency, quality, or modulation level in any way.

3 Receiver Design

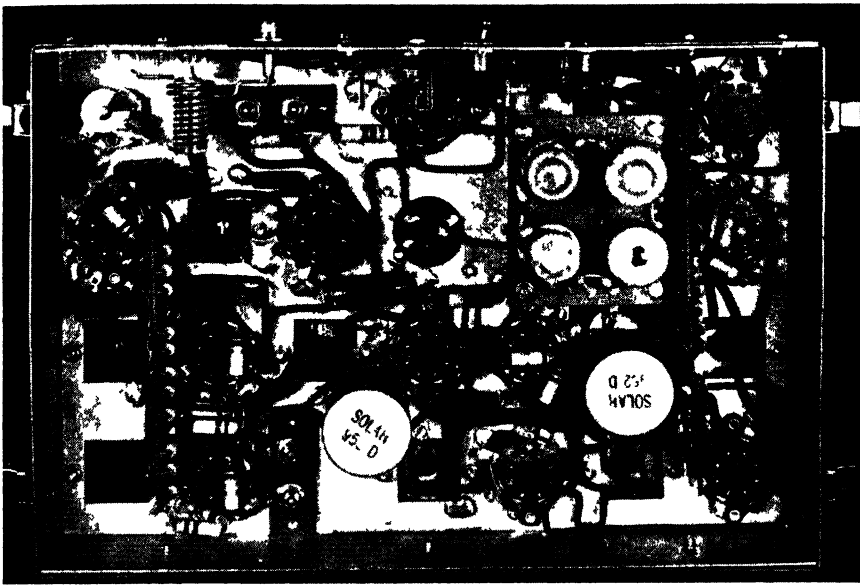
The 11-UF (Ed. 3) receiver is an 11-tube crystal-control single-frequency, frequency modulation superheterodyne receiver designed particularly for the reception of frequency-modulated signals of the type



Layout diagram of 11-UF receiver.

generated by the 25-UFM mobile transmitter. Some pertinent characteristics are:

Frequency range: 30–40 megacycles.
Type of signal: Frequency modulated.
Frequency deviation: ± 15 kilocycles.
Audio response: ± 3 db. 300–3000 cycles (sharp cutoff filter attenuates frequencies above 3000).
Tube complement: (2) 6AC7; (2) 6K8; (1) 6SH7; (1) 6SJ7; (2) 6H6; (1) 6V6; (1) 6SL7GT; (1) 6K6GT.
Power supply: External—usually vibrator VPA-3A.
Power input: 6 v. @ 6.5 amps. 39 watts (with VPA-3A).
Output impedance: 500 ohms.
Mounting: Snubbing-type rubber shock mountings.
Control: Remote—co-ordinated with 25-UFM control.



Subchassis view Link 11-UF receiver. (Courtesy NYA and South Portland, Maine.)

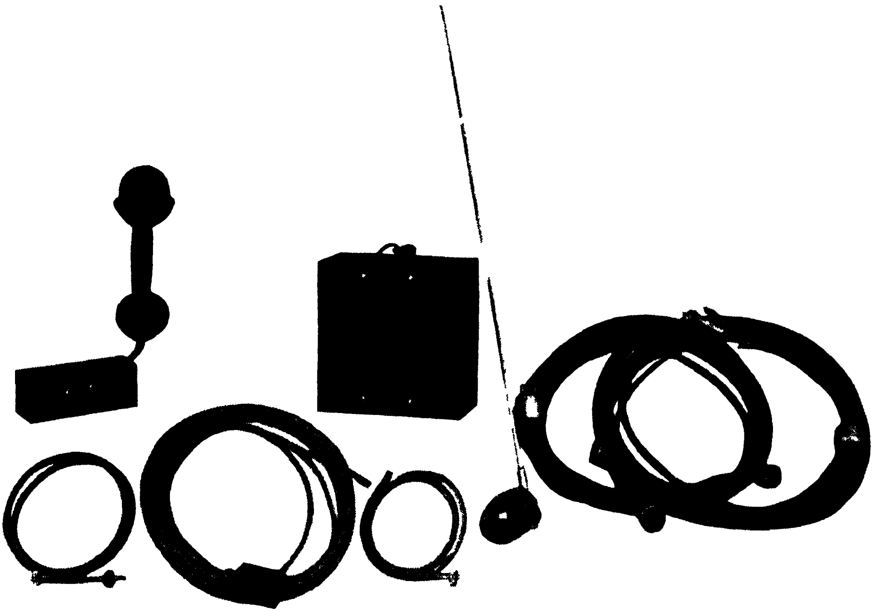
Weight: 17½ pounds.
Size: 9 by 13 by 7½ inches high.
Power output: 1½ watts, 2½ watts peak.

The 11-UF (Ed. 3) receiver utilizes eleven tubes in a unique multiple superheterodyne circuit. The tube types and their uses are:

1 Type 6AC7 or 6SH7	RF amplifier.
1 Type 6K8	First detector.
1 Type 6V6	Crystal oscillator multiplier.
1 Type 6SH7 or 6SG7	IF amplifier.
1 Type 6K8	Second detector, crystal oscillator.
1 Type 6SJ7	First limiter.
1 Type 6AC7	Second limiter.
1 Type 6H6	Discriminator.
1 Type 6H6	Squelch rectifier.
1 Type 6SL7GT	First audio, squelch.
1 Type 6K6GT	Audio output.

The locations of the tubes and interstage transformers are shown on the location chart in the cover of each receiver. Two quartz crystals are employed to insure stable receiving conditions under all variations of temperature and humidity as well as under the severe vibration encountered in mobile service. The double IF system makes possible excellent band-pass characteristics with a very favorable image ratio.

Three tuning meter jacks are located on the receiver chassis. One is for measuring the grid current of the first limiter and thus indicating reso-



Accessory equipment for mobile FM installation. (Courtesy F. M. Link.)

nance in all the preceding stages; another is for measuring the grid current of the last limiter; the third is to permit adjustment of the balance of the discriminator circuit. The first two require the use of a zero to one hundred microampere meter, while the third requires a fifty or one hundred microammeter, center zero type preferred.

Receiver Power Supply. The VPA-3A power supply is a synchronous vibrator B supply designed for use with the 11-UF receiver in mobile applications. It incorporates the most efficient and long-lived vibrator and circuit available, and affords a very reliable and economical method of obtaining B voltages. Its characteristics are:

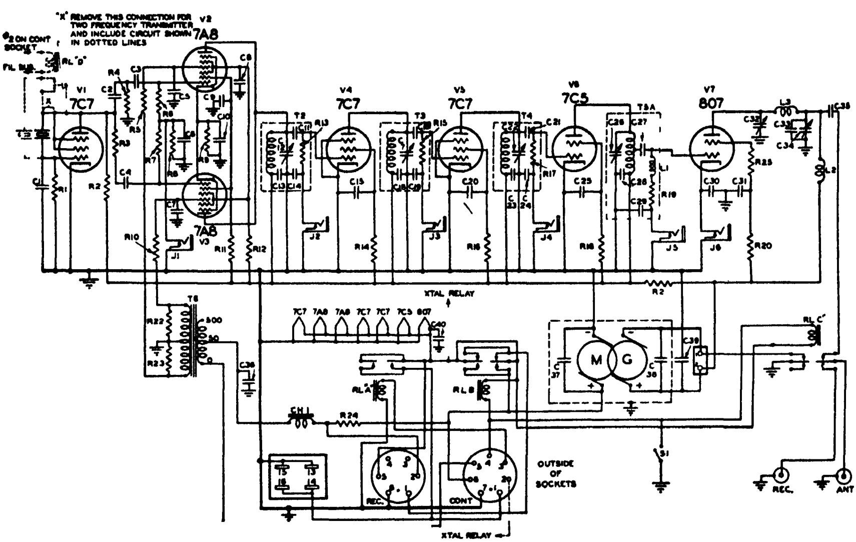
Input: 6.0 v. @ 3.5 amp.
Output: 250 v. @ 60 ma.
Type of vibrator: Synchronous Type 525.
Mounting: Base, with removable cover for servicing.
Size: $8\frac{1}{2}$ by $4\frac{1}{4}$ by 5 inches high.
Weight: $7\frac{1}{4}$ pounds.

4 Equipment Accessories

Each FMTR equipment contains, in addition to the transmitter, receiver, and power supply described above, all accessories to complete the mobile installation. These include:

1. Remote control head with receive and transmit pilot lights, squelch switch, and volume control.
2. Push-to-talk handset with Extensicord cable and hang-up bracket.
3. Receiver and transmitter control cables, primary power cable, antenna cables, and all cable connectors for utilizing same.
4. Mobile whip antenna with universal mounting.
5. Loudspeaker.
6. Installation kit including screws, bolts, circuit breaker, suppressors, condensers, cable clamps, and all items necessary to complete the installation.
7. Instruction book.

The remote controls and cables are so arranged that complete operation of the equipment may be carried on from the remote point with a minimum of effort. No circuit or tuning adjustments other than off-on switches and a volume control are necessary. The bulk of the equipment may be located in any convenient storage space. All cable connections are of the plug-in type for rapid installation, service, and interchange. Control cables carry no high voltages or heavy currents.



Circuit diagram of 25-UFM transmitter.

5 Circuit Analysis and Parts List of 25-UFM Transmitter

The 25-UFM (Ed. 2) transmitter uses the phase-shift method of obtaining frequency deviations, and therefore exhibits considerably different characteristics from the usual amplitude-modulated units. Intelligence is conveyed in variations of the constant amplitude carrier frequency about a mean value, as contrasted in amplitude modulation to intelligence being contained in amplitude variations of the constant

frequency carrier wave. The use of the phase-shift method of frequency modulation allows direct crystal control of the mean carrier frequency, a necessity in unattended and mobile equipment. It necessitates, however, considerable frequency multiplication after the modulator to generate sufficient frequency deviation. A number of small low-drain tubes are used for this function, and a total frequency multiplication of 32 times is effected.

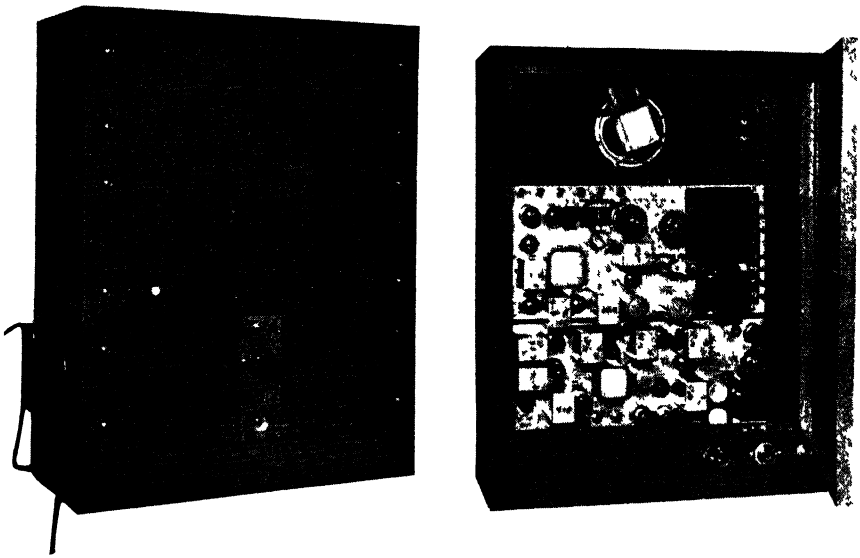
In working with FM transmitters, certain handicaps are encountered that make unusable many of the rules of thumb that have been helpful in servicing amplitude-modulated equipment. Oscilloscopes are of little value in checking, since no change of pattern is discernible during modulation. In fact, modulation is accompanied by no readily measureable change of any kind in the RF output of the transmitter.

Circuit Analysis. Crystal oscillator V1 is a pentode receiving tube (7C7) connected as a triode and operating in a resistance-coupled aperiodic oscillator circuit. No tuning is necessary when changing frequency. The crystal is connected between grid and plate and is of the low-drift "AT" cut type operating at the thirty-second subharmonic of the output frequency. Since the output frequency range is 30–40 megacycles, the crystal frequency lies between 937.5 kilocycles and 1250 kilocycles.

The injection grids of the two 7A8 balanced modulators V2 and V3 are driven from the plate of the oscillator through phase-shifting networks designed to advance the phase of one grid by approximately 45 degrees and to retard the phase of the other by approximately 45 degrees. The plate currents of V2 and V3 will therefore be about 90 degrees out of phase and are so proportioned as to be roughly equal in magnitude. The two currents add vectorally to produce a resultant voltage across T2.

The control grids of the balanced modulators V2 and V3 are connected to the secondary of the push-pull audio transformer T6. This transformer is driven directly from the microphone, and microphone current is taken from the 6-volt primary source through the filter network R24, CH1, and C36. The modulator grids are fed through the frequency-correcting networks R5, C5, and R10, C7. These RC combinations attenuate the audio-frequency range above 2000 cycles so that excessive frequency deviation is not obtained. Resistors R22 and R23 are terminating resistors for the secondary of the microphone transformer T6. Cathode bias and screen voltages are obtained in a conventional manner.

As audio voltages are applied in push-pull to the control grids of the modulators V2 and V3, their plate currents are varied about mean values, and as one increases the other decreases. The resultant current in T2 is shifting in phase (and frequency) with the audio frequency fed into the microphone circuit. Some amplitude variations are also introduced, but



Equivalent equipment designed for fixed station use (Link type 25-UFS instead of 25-UFM) Instead of receiver vibrator and transmitter dynamotor power supplies, a vacuum tube rectification circuit is provided to use 115-volt 60-cycle single-phase current.

these may be neglected since they are wiped out by the limiting action of the succeeding stages.

Frequency Multipliers. The frequency deviation which may be produced in a balanced modulator, such as described above, is relatively small, usually not more than a value equal to the modulating frequency without encountering severe distortion. To get sufficient deviation (plus and minus 15 kilocycles) the frequency of the modulated wave must be multiplied considerably, in this case by a factor of 32. This is accomplished by two quadruplers V4 (7C7) and V5 (7C7), and a doubler V6 (7C5). All three tubes act as Class C radio-frequency amplifiers with grid leak bias. The grid drive in each case is well above saturation so that slight changes in tuning or reduction in tube emission can have little effect on succeeding stages. Up to this point, all stages use receiving-type tubes working at relatively low plate and filament currents.

Power Amplifier. The power amplifier V7 utilizes an 807 beam transmitting tube as a Class C amplifier. Grid leak bias is used and, as in the preceding stages, a jack is provided to meter the grid current for alignment and testing. The plate tank and antenna circuit is of the Pi type for harmonic suppression and ease of adjustment. This circuit consists of the plate tuning condenser C32, the tank coil L3, antenna loading condensers C33 and C34. The output is fed through the blocking condenser C35 to the antenna relay RL"C."

Control and Power Circuits. The 25-UFM (Ed. 2) transmitter has sufficient relay circuits for complete remote control, and in addition is designed for the 11-UF receiver. The normal operating sequence is as follows:

1. Relay "A" is energized by applying "hot" 6 volts to contact 3 on the control plug. This is accomplished in the remote control unit by turning on the volume control switch.
2. Relay "A" energizes transmitter filaments, receiver filaments through contact 5 on the receiver plug, and the receiver power supply through back contacts on Relay "B" and contact 1 on the receiver plug. The receiver is now in full operation and the transmitter filaments are warm. Antenna connection is made to the receiver through back contacts of relay "C."
3. In order to transmit, relays "B" and "C" are energized through contact 4 on the control plug and the microphone push-to-talk button. The transmitter may also be turned on by means of a toggle switch located on the right-hand end of the chassis near the control cables. This switch is used when tuning or making other adjustments.
4. Relay "B" breaks the receiver power-supply primary voltage, thus muting the receiver. It also applies primary energy to the dynamotor MG which supplies the entire transmitter with high voltage.
5. Relay "C" transfers the antenna from receiver to transmitter and closes the +B circuit from transmitter dynamotor to the transmitter circuits. This high-voltage break is necessary to key the transmitter rapidly and allow rapid transfer from transmit to receive. The dynamotor MG is hash filtered by condensers C37 and C38. C39 is a high-voltage high-capacity condenser to reduce ripple to a satisfactory level.

Parts List for Circuit Diagram of 25-UFM Transmitter

C 1 - 150 mmfd. MO
C 2 —10 mmfd. MO
C 3 —100 mmfd. MO
C 4- 100 mmfd. MO
C 5 .002 mfd. MW
C 6--.01 mfd. 400 v.
C 7 .002 mfd. MW
C 8 .05 mfd. 600 v.
C 9 .05 mfd. 600 v.
C10 .05 mfd. 600 v.
C11--100 mmfd. MO. Part of T2
C12- -76 mmfd. variable. Part of T2
C13 —.05 mfd. 600 v. Part of T2
C14 .002 mfd. MW. Part of T2
C15- .002 mfd. MW
C16—100 mmfd. MO. Part of T3
C17—44 mmfd. variable. Part of T3
C18—.002 mfd. MW. Part of T3
C19--.002 mfd. MW. Part of T3
C20- .002 mfd. MW
C21—100 mmfd. MO. Part of T4
C22—44 mmfd. variable. Part of T4
C23—.002 mfd. MW. Part of T4
T5A—Doubler plate tank
T6 —C-1981 audio trans.
L1—2.5 MH RF choke
L2- 2.5 MH RF choke
L3 --PA, plate tank coil
CHI TR-957 choke
MG-Type E3—Dynamotor
R 1 .5 megohm ½ w.
R 2—50 M ohms 1 w.
R 3 20 M ohms 1 w.
R 4--20 M ohms 1 w.
R 5 50 M ohms ½ w.
R 6--50 M ohms 1 w.
R 7- 50 M ohms 1 w.
R 8—1000 M ohms 1 w.
R 9 -250 ohms 1 w.
R10- 50 M ohms ½ w.
R11—50 M ohms 1 w.
R12- 50 M ohms 1 w.
R13—.25 megohm ½ w. Part of T2
R14—100 M ohms 1 w.
R15—.25 megohm ½ w. Part of T3
R16—100 M ohms 1 w.

C24—.002 mfd. MW. Part of T4
C25—.002 mfd. MW
C26—44 mmfd. variable. Part of T5
C27—.002 mfd. MW. Part of T5
C28—.002 mfd. MW. Part of T5
C29—.002 mfd. MW
C30—.002 mfd. MW
C31—.002 mfd. B-10
C32—25 mmfd. variable Millen
C33—100 mmfd. B-10
C34—140 mmfd. Variable
C35—.002 mfd. B-10
C36—25 mfd. 50 v. Nonpolarized
C37—.01 mfd. B-10
C38—.01 mfd. B-15
C39—4 mfd. 600 v. XC-64
C40—.002 mfd. MW
T2—Amplifier plate tank
T3—Multiplier plate tank
T4—Multiplier plate tank
R17—.25 megohm ½ w. Part of T4
R18—100 M ohms 1 w.
R19—15 M ohms 1 w.
R20—15 M ohms 10 w.
R21—4 M ohms 25 w.
R22—25 M ohms ½ w.
R23—25 M ohms ½ w.
R24—300 ohms 1 w.
R25—15 ohms 1 w.
J1—Closed circuit jack
J2—Closed circuit jack
J3—Closed circuit jack
J4—Closed circuit jack
J5—Closed circuit jack
J6—Closed circuit jack
S1—S.P.S.T. test switch
RL"A"—#205 AM fil. relay
RL"B"—#204 AM plate relay
RL"C"—#2000 ant. relay
RL"D"—AS-crystal relay

6 Circuit Analysis and Parts List of 11-UF Receiver

While the 11-UF is designed to receive signals wherein the intelligence is conveyed in the variations of carrier frequency about a mean frequency instead of variations in the amplitude of the carrier about a mean level as in amplitude modulation, there are only three fundamental differences between amplitude and frequency modulation receivers.

The first difference is in the band-pass characteristics. Since the carrier frequency varies over a band of plus and minus 15 kilocycles about the mean carrier frequency, the receiver has to accept a band at least 30 kilocycles wide. Thus the intermediate-frequency transformers are designed to pass a wide band; being tightly coupled and loaded with resistors across the windings.

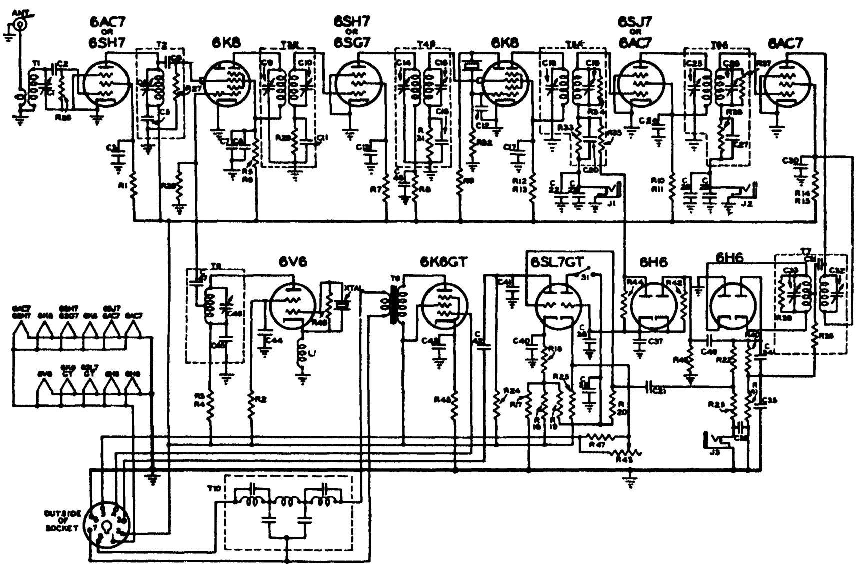
The second difference is that, since only variations in frequency are to be converted into intelligence, amplitude variations of the signal must be removed. This function is accomplished by the limiters. They are, in effect, saturated amplifiers so that increasing the input to them above a certain level will cause no increase in their output. Thus they limit the magnitude of the signal applied to the discriminator to a constant level. The excellent signal-to-noise ratio of the 11-UF receiver is largely due to the use of two cascaded limiters. Thus on signals too weak to effectively saturate the first limiter, the second limiter is already saturated and ironing out whatever amplitude noise variations the first limiter has permitted to pass.

The third difference is in the method of detection; that is, the conversion of frequency variations into audio frequencies. This function is accomplished by the discriminator transformer (T7) and the 6H6 detector.

This device is similar in operation to certain types of automatic frequency control discriminators used in broadcast receivers.

Circuit Analysis. The antenna input of the 11-UF is designed to feed from a 70-ohm concentric line. A 6AC7 or 6SH7 serves as a high-gain RF amplifier with tuned circuits in both grid and plate for maximum efficiency. The output of the RF amplifier is converted to the first IF frequency of 5000 kilocycles in the following 6K8 first detector by beating against the input of the local oscillator.

The local oscillator is a crystal-controlled beam-power pentode (6V6). The tank circuit is tuned to the crystal which is cut to a frequency that is



Circuit diagram of 11-UF receiver.

the operating frequency subtracted by 5000 kilocycles and then divided by 8. For example in the case of South Portland, Maine, operating on 39,180 kilocycles it computes to 39,180 minus 5000, then divided by 8 to give 4272.5 kilocycles fundamental crystal frequency. A portion of the voltage appearing across it is injected into the first detector to obtain the desired frequency conversion.

One stage of amplification on 5000 kilocycles is provided, using a 6SH7 or 6SG7 tube as the amplifier. Its output is applied in turn to the second 6K8 converter where the frequency is changed to the final intermediate frequency of 456 kc. This is accomplished by using the oscillator portion of the 6K8 tube as an aperiodic oscillator with a 5456-kilocycle crystal connected between plate and grid. This crystal is of the same high quality as the signal frequency crystal.

The beat between the 5000-kilocycle output of the first detector and the 456-kilocycle crystal results in the final intermediate frequency of 456 kilocycles which is amplified, passed through the IF transformer T5A, and applied to the grid of the first limiter (6SJ7 or 6AC7).

The two following stages utilize 6SJ7 and 6AC7 tubes respectively as current-limiting amplifiers, and the circuits and actions of the two stages are identical. The tubes are operated at low plate and screen voltage (75 volts) and without bias, except that derived from the grid leak and condenser combinations, R33, C20, and R36, C27. These stages act as Class C amplifiers, giving no increase in output current or voltage once the impressed grid voltage has exceeded a threshold value of about 2 volts RMS. Voltages above this value cause increasing rectification in the grid circuit, automatically setting up a bias to limit the peak plate current. Due to the low plate and screen voltages the saturation occurs at a low level of grid voltage. The time constant of the grid leak and condenser is chosen to be long compared to the IF frequency (456 kilocycles), but short enough to follow rapidly fluctuating, high frequency noise peaks.

By cascading two such stages, the limiting effect of one tube is multiplied by the limiting effect of the other, and essentially perfect limiting is obtained. Furthermore, by properly proportioning the circuit constants of the first limiter, the input to the second limiter grid is maintained at the optimum voltage for most effective action. Sufficient gain is incorporated in the receiver so that the smallest incoming signal which could be considered comparable with the noise generated in the grid circuits of the first tube causes saturation of the second limiter. The first limiter is in turn saturated by signals of 0.25 uv. or over.

The output of the second limiter, free of amplitude variations, is fed through the discriminator transformer T7 to the 6H6 balanced detector. The primary and secondary of the discriminator transformer are coupled both inductively and capacitively. Two voltages of different phase are thus applied to each half of the 6H6. The discriminator is so adjusted that, when a steady carrier (456 kilocycles) is received, the voltage applied to the two halves of the 6H6 cause equal and opposite currents to flow through the load resistors R40 and R41. Thus the resultant voltage appearing across the two resistors is zero.

If any other frequency than 456 kilocycles appears at the discriminator, the out-of-phase components of the 6H6 will be unbalanced, and a positive or negative resultant voltage will appear cross R40 and R41. The sign and magnitude of this voltage will follow the impressed IF frequencies rather than amplitude changes in it. In this manner, an audio voltage (varying in amplitude) is derived from the frequency variations of the incoming signals. The fact that the resultant DC output voltage

of the discriminator and detector should be zero, when a carrier of the correct frequency is impressed, is useful to assist in tuning this transformer. A jack is connected through filter resistors R23 and R22 to the output of the 6H6, so that a sensitive microammeter (0–100 μ amp. center zero type preferred) may be plugged in and the necessary adjustments made for zero reading.

The audio-frequency output of the discriminator is passed through a voltage divider network consisting of R22 and R23 where the output of the discriminator is reduced to prevent overloading of the 6SL7GT audio amplifier. The audio frequency is than applied to the second grid (G2) of the dual triode audio amplifier 6SL7GT. The first triode section of the 6SL7GT is used to disable the second triode section when no carrier is received. The actuating voltages for the squelch circuit are obtained from two sources. One is rectified limiter grid current and is dependent on signal or noise level. The other is the high frequency audio component at the output of the discriminator and is dependent only on signal-to-noise ratio.

PARTS LIST FOR CIRCUIT DIAGRAM OF 11-UF RECEIVER

C 1—44 mmfd. variable ATR-1110
C 2—100 mmfd. mica
C 3—.002 mfd. mica
C 4—44 mmfd. variable. Part of T2
C 5—.002 mfd. mica. Part of T2
C 6—.002 mfd. mica. Part of T2
C 7—.002 mfd. mica
C 8—.05 mfd. 400 v. tub.
C 9—Variable cond. Part of T3B
C10—Variable cond. Part of T3B
C11—100 mmfd. mica. Part of T3B
C12—5 mmfd. mica
C13—.05 mfd. 400 v. tub.
C14—Variable cond. Part of T4B
C15—Variable cond. Part of T4B
C16—100 mmfd. mica. Part of T4B
C17—.05 mfd. 400 v. tub.
C18—Variable cond. Part of T5A
C19—Variable cond. Part of T5A
C20—100 mmfd. mica. Part of T5A
C21—.005 mfd. 600 v. tub.
C22—.05 mfd. 400 v. tub.
C23—.05 mfd. 200 v. block
C24—.05 mfd. 400 v. block
C25—Variable cond. Part of T6A
C26—Variable cond. Part of T6A
C27—100 mmfd. mica. Part of T6A
C28—.05 mfd. 400 v. tub.
C29—.05 mfd. 200 v. block
C30—.05 mfd. 400 v. block
C31—500 mmfd. mica. Part of T7
C32—Variable cond. Part of T7
C33—Variable cond. Part of T7
C34—100 mmfd. mica
C35—100 mmfd. mica
C36—.05 mfd. 400 v. tub.
C37—.25 mfd. 200 v. tub.
C38—.05 mfd. 200 v. block
C39—.05 mfd. 400 v. block
C40—10 mfd. 50 v. electro
C41—500 mmfd. mica
C42—.005 mfd. 600 v. tub.
C43—20 mfd. 25 v. electro
C44—.002 mfd. mica
C45—.002 mfd. mica. Part of T9
C46—44 mmfd. variable. Part of T9
C47—.002 mfd. mica. Part of T9
C48—.05 mfd. 400 v. tub.
C49—100 mmfd. mica
S1—S.P.S.T. toggle switch (squelch)
L1—Osc. cathode coil
R 1—100 M ohms 1 w.
R 2—100 M ohms 1 w.
R 3—60 M ohms 1 w.
R 4—60 M ohms 1 w. Parallel with R3
R 5—75 M ohms 1 w.
R 6—75 M ohms 1 w. Parallel with R5
R 7—100 M ohms 1 w.
R 8—10 M ohms 1 w.

R 9—150 M ohms 1 w.
R10—50 M ohms 1 w.
R11—50 M ohms 1 w. Parallel with R10
R12—75 M ohms 1 w.
R13—75 M ohms 1 w. Parallel with R12
R14—50 M ohms 1 w.
R15—50 M ohms 1 w. Parallel with R_{14}.
R16—50 M ohms 1 w.
R17—20 M ohms 1 w.
R18—5 M ohms 1 w.
R19—250 M ohms 1 w.
R20—1 megohm 1 w.
R22—250 M ohms 1 w.
R23—50 M ohms 1 w.
R24—250 M ohms 1 w.
R25—100 M ohms 1 w.
R26—1 megohm ½ w.
R27—1 megohm ½ w. Part of T2
R28—50 M ohms ½ w.
R29—100 M ohms ½ w. Part of T3B
R31—100 M ohms ½ w. Part of T4B
R32—50 M ohms ½ w.
R33—100 M ohms ½ w. Part of T5A
R34—50 M ohms ½ w. Part of T5A
R35—500 M ohms ½ w. Part of T5A
R36—100 M ohms ½ w. Part of T6A
R37—50 M ohms ½ w. Part of T6A
R38—20 M ohms ½ w. Part of T7
R39—50 M ohms ½ w. Part of T7
R40—100 M ohms ½ w.
R41—100 M ohms ½ w.
R42—5 megohm ½ w.
R43—25 M ohm squelch pot. #9124 or H4013
R44—5 megohm ½ w.
R45—1000 ohms 1 w.
R46—100 M ohms ½ w.
R47—7500 ohms ½ w.
R48—500 M ohms ½ w.
J1—Closed circuit tuning meter jack (T5A)
J2—Closed circuit tuning meter jack (T6A)
J3—Closed circuit balance meter jack
T 1 —Ant. coil assembly
T 2 —RF coil assembly
T 3B—5 MC IF coil assembly
T 4B—5 MC IF coil assembly
T 5A—456 KC IF coil assembly
T 6A—456 KC IF coil assembly
T 7 —Disc. coil assembly
T 8 —#6226 output transformer
T 9 —Osc. coil assembly
T10 —#7316 audio filter

7 Installation of Entire Mobile Equipment

The location of the various units making up the FMTR assembly has considerable bearing on the subsequent performance and servicability of the equipment and should therefore be carefully planned.

The location and installation of the antenna constitutes an important factor in the placement of equipment and usually should be considered first. The length of the antenna is not critical, but should be approximately a quarter-wave length long for best results. Two sizes of antenna are used, one about 6 feet long and the other about 7 feet long. The shorter ones are shipped with sets for frequencies above 35 megacycles, while the longer ones are shipped with sets for frequencies below 35 megacycles.

Vertical antenna on cars, trucks, tanks, and the like, exhibit pronounced directional effects. The best transmission and reception will be experienced to that side of the antenna on which lies the greatest mass of the car. Therefore, in the normal case, where the antenna is mounted at the rear of a car, the best communication will be possible in the direction in which the car is heading. This effect can be minimized and the efficiency also greatly improved by:

1. Mounting the antenna as high on the metal body as practical.
2. Mounting the antenna as near to the center of mass of the car as practical.
3. Mounting the antenna as clear of paralleling sides of the metalwork as practical.

After a tentative location for the antenna base has been decided on, an inspection should be made to see that sufficient space is available near the antenna base to install and service the transmitter, receiver, and vibrator power supply. It is preferable to have the transmission line between the transmitter and antenna short, but antenna height should not be sacrificed to accomplish this end. The three units should be placed so that they can be readily removed from their bases when desired and so that all tuning adjustments may be conveniently reached when in place. A typical layout is indicated on the installation chart. It is wise in locating the units to try the plug-in cables to make sure that the chassis are sufficiently close together and properly located for ready insertion and removal of all plugs.

Installing the Antenna. When the location for the antenna has been decided on, completely disassemble the universal mounting. Hold one of the round bakelite discs firmly against the body of the car or truck and, with a sharp-pointed instrument, scribe markings on the body through the six small mounting holes of the bakelite disc. Drill and tap these holes with a No. 30 drill and 8-32 tap respectively. By drawing diagonals between these holes, locate the center of the mounting space and drill or punch a hole, $\frac{3}{4}$ to 1 inch in diameter, in the car or truck body. The antenna and mounting may now be assembled.

To assemble the antenna mounting, place one bakelite disc on the outside of the body over the holes just drilled, and screw into place with the 8-32 machine screws provided. Put the other bakelite disc in place over the screws extending through the inside of the car or truck body. The six mounting screws have been tapped through the body to provide a 6-point ground of low RF resistance. Before tightening the 8-32 nuts and lock washers on these screws, bind them together with a piece of braid for convenience in grounding the outer conductor of the antenna transmission line. Care should be taken to keep this grounding braid as near the outer periphery of the bakelite disc as possible, so that no shorts will occur later when the remainder of the mounting is assembled.

Reassemble the mounting as originally shipped, taking care that the toothed portions of the mounting face each other and that the corrugated face of the mounting bears on the outside bakelite disc. The antenna may now be placed in its socket and locked in position by means of the nut provided. Adjust the antenna so that it is in a vertical position, and, while maintaining it in that position, firmly tighten the larger nut and lock

washer on the stud extending through the inside of the mounting. Considerable tension should be placed on this nut, and it is advisable to retighten it after the mounting has had a day or two to settle in position. This precaution will guarantee that the mounting will not loosen after repeated blows on the antenna under high-speed travel. One nut and solder lug remain to be used on installation of the antenna transmission line.

Mounting the Transmitter. Before the transmitter can be permanently mounted, the base plate must be disassembled from the sub-base plate. To do this, first remove the transmitter chassis from the base in the following manner. Uncouple the snap-slides at the right-hand end of the transmitter base and give each a quarter turn to clear the transmitter chassis. Loosen the locking screws at the left-hand end of the mounting (a turn or two is sufficient). Lift the right-hand end of the chassis slightly and slide to the right, completely removing the chassis. The base plate may be removed from the sub-base by removing the four elastic stop nuts at the corners of the mounting. Removing the base plate will expose the surface of the sub-base plate for mounting.

Using the sub-base plate as a template, drill six holes through the metal floor of the car or truck, using a No. 31 drill. With the appropriate length self-tapping screws (two lengths are furnished), fasten the sub-base firmly to the floor. Any rug, mat, or insulation material may be left in place so long as the screws engage the metal body. Be sure that the grounding braid will be at the right rear of the transmitter when mounted. Reassemble the base on the sub-base, tightening the elastic stop nuts only enough to put slight compression on the rubber grommets.

Mounting the Receiver. The procedure used in mounting the receiver is similar to that used in mounting the transmitter. The receiver chassis is readily removed from its base by loosening the four catches. In reassembling the base after mounting, be sure that the flexible grounding strip is in place next to the elastic stop nut so that an effective ground is made through the stud holding the rubber grommet.

Mounting the Receiver Power Supply. The receiver power supply is mounted directly on the floor of the car or truck without shock mounts. Remove the cover of the power supply and, using the bottom cover of the unit as a template, drill four No. 31 holes. Screw the bottom firmly to the metal floor with the appropriate length self-tapping screws.

Mounting the Control Unit and Loudspeaker. The remote control unit may be mounted wherever desired in a location convenient to the operator of the equipment. It was primarily designed for mounting under the edge of the car or truck instrument panel near the center of the vehicle, so that either the driver or the person sitting with him could reach it con-

veniently. A location should be chosen that will permit clear access to the rear of the control head for attaching the necessary cables.

When the desired location has been chosen, remove the mounting bracket from the control head by removing the two 6-32 machine screws and lock washers on the bottom of the unit. The bracket may then be removed and readily mounted under any reasonably flat and horizontal surface by means of self-tapping screws. A number of holes are punched in the bracket, which may be used for a drilling template. Select two convenient ones and drill two No. 31 holes for No. 8 self-tapping screws. Mount the bracket securely and then slip the control head into place over the bracket, fastening it to the bracket by means of the two 6-32 screws previously removed.

The handset is shipped wired to the control head. The handset mounting cup or bracket should now be mounted on a vertical surface in some convenient location near the control head. This may be done by use of two No. 31 holes and the two long No. 8 self-tapping screws provided.

Depending on the type of installation expected, either of two types of speakers may have been included in the shipment. Both are permanent magnet dynamic units; the first a 5-inch model for back-of-grill mounting and the other a 6-inch model in a metal case for bulkhead mounting. Both types have a cable and three-prong plug attached for connection with the control head.

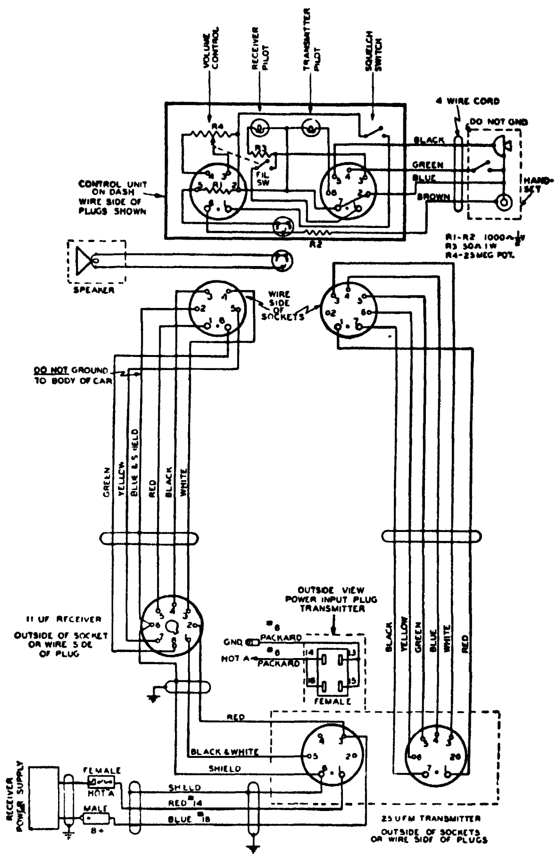
The back-of-grill speaker is used in the majority of new installations in pleasure cars and is normally shipped with the equipment unless it is known that the other type is needed. The 5-inch unit easily fits nearly all modern cars and may be readily mounted by means of the accessories provided.

First determine as closely as possible where the speaker will be placed, then force a pointed instrument through the grill cloth for two holes at the extreme right and left sides of the speaker rim. Use the ⅜-inch by 1¼-inch chrome-plated strips and 2-inch No. 8 oval-head screws provided for mounting, by passing the screws through the strips, grill, and rim of speaker. Use lock washers and nuts back of rim of speaker, and tighten securely.

For commercial or military vehicles which have no speaker grill, the 6-inch speaker is supplied in a metal housing for mounting behind the instrument panel on the dashboard. Determine a clear space for the speaker and drill a ⅜-inch hole in the dash in the center of that space. The speaker is mounted by assembling the 5⁄16-inch by 3-inch stud into the back of the speaker magnet and bolting the assembly in place on the car with the appropriate washer, lock washer, and nut.

Installing the Cables. Five separate cables are provided for each instal-

lation as follows: (1) primary power cable, (2) transmitter control cable, (3) receiver control cable, (4) transmitter to receiver antenna cable, and (5) transmitter to antenna cable. All cables are made up as completely as possible and fully tested at the factory for maximum convenience at the time of installation.



Interconnections between units of equipment. (Courtesy F. M. Link.)

The installation chart indicates clearly the use of each of these cables. Their installation should be made carefully to avoid possible chafing or rubbing that might eventually break through the insulation. Care should be taken to insure that in placing the cables no strain or pull exists on any cables that would tend to disengage plugs or connectors under vibration. Where cables are run under the frame of the vehicle, they should be clamped at frequent intervals high in the frame to eliminate possibility of damage when traversing rough country. All cables are fully waterproof.

The main circuit breaker should be normally mounted near the battery or main source of primary energy so as to afford maximum protection in case of shorts, including any in the primary power cable. The circuit breaker supplied will open on shorts or overloads, but will automatically reset itself in a few seconds. If the short or overload still exists, the breaker will open again and repeat the cycle with a loud clicking noise indefinitely until the fault is found and repaired. This circuit breaker may be mounted on any flat surface with two No. 8 self-tapping screws.

The primary power may be taken directly from the battery or from some point such as the engine starter which has a heavy direct connection to the battery already in place. The latter step often makes battery maintenance more convenient by leaving only one heavy lug on each post of the storage battery.

Tuning and Operation. The equipment as delivered is tuned and ready for operation. A few checks must first be made, however, to make sure that the equipment is ready for operation before power is actually applied. Unless otherwise marked, all equipment is shipped connected for use with a battery whose positive terminal is grounded. If the negative terminal of the battery is grounded, the receiver power supply and transmitter dynamotor must be properly reconnected.

To adjust properly the vibrator power supply Type VPA-3A for the appropriate battery ground, remove the power supply cover. On the top of the vibrator shield can be seen plus and minus signs. It will be noticed that the vibrator can be plugged into its socket in two positions, 180 degrees apart. When the minus sign is nearest the power transformer, the power supply is properly connected for a primary source with the negative grounded. No other adjustments are made to the power supply.

To change polarity, the transmitter must first be removed from its base and turned upside down. At one end near the control relays will be seen a small bakelite strip with two screw terminals marked 1 and 2. For positive ground operation, the red wire should be connected to terminal No. 1, while the black wire is connected to terminal No. 2. For negative ground operation, the black wire should be connected to terminal No. 1, while the red wire is connected to terminal No. 2.

8 Tuning and Adjustment of 25-UFM Equipment

The 25-UFM transmitter is accurately adjusted at the factory for the specified operating frequency and only a brief tuning procedure need usually be followed on installation. For routine maintenance checks however, a more thorough checkup of transmitter performance is desirable to locate tubes that might be getting weak and should be replaced. A large factor of safety exists in the output of each stage of the transmitter

so that no drop in power output will result from one or more tubes depreciating to a considerable extent. A routine check will, moreover, indicate these weak tubes before any loss in performance is noticed.

Six test meter jacks are located on the front of the transmitter chassis. They afford a complete checkup on the condition of the unit. Those numbered from one to five read the grid currents of the modulators, first quadrupler, second quadrupler, doubler, and PA respectively. The sixth jack reads the PA cathode current and is used to adjust the PA plate and antenna loading circuits. A 0–1 DC milliammeter is used to read the currents in jacks one through four, a 0–5 or 0–10 DC milliammeter for jack five and a 0–250 DC milliammeter for jack six. The numbering of the jacks and RF transformers is so co-ordinated that the meter is plugged into jack two to tune transformer T2, and so on.

All tuning adjustments, except for the output circuit, are made for maximum grid current in each successive stage, and the following table will act as a guide to normal readings. The values given are average at a battery supply voltage of 6.3 volts. Higher or lower voltages will, of course slightly alter readings.

Jack	Transformer	Circuit	Current
1		7A8 Modulator grids	0.4 ma.
2	T2	7C7 1st quadrupler grid	0.5 ma.
3	T3	7C7 2nd quadrupler grid	0.5 ma.
4	T4	7C5 Doubler grid	0.25 ma.
5	T5	807 P.A. grid	3.0 ma.

A substantial decrease below any of these values indicates a weak tube, probably in the stage whose plate circuit is being tuned, and that tube should be replaced.

Service and Test. Maintenance of the 25-UFM transmitter consists primarily of routine tube replacements when necessary. All components are operated under conditions which insure long life, and failures have been rare in field service. Since every stage is metered, nearly all possible conditions will be reflected in the meter readings, and servicing is reduced to simple deduction.

By comparison with the above table of currents or by comparison with values known from experience to be normal, trouble may be quickly isolated in a particular tube or stage. The procedure already outlined will readily check the condition of all tubes except the 7A8 balanced modulators. These tubes and the entire modulator circuit may likewise be checked by the same meter readings. If both modulator tubes and retune T2 are removed, the carrier will be delivered entirely by the one remaining modulator tube. The corresponding grid current of the first quadrupler (as read in jack 2) should be approximately 0.6–0.7 ma. This value should be very nearly the same, using either modulator tube in either socket.

Likewise, the modulator grid currents (as read in jack 1) should be nearly alike. As much as a 50 per cent variation in the modulator grid current readings between the two modulator sockets may be considered normal, since they can be actually balanced at only one frequency in the band, and at either end of the 30–40 megacycles operating range some unbalance must be expected. Since the tubes are operating under saturated Class C conditions, such variations in grid current are not significant. When both modulator tubes are placed in their sockets and T2 retuned, the output of the combined modulators (jack 2) will drop to about 0.5 ma. due to the phase relationship of the two modulator plate currents and their consequent balancing action. The foregoing test, if normal, indicates several things. First, it shows that the modulator tubes are both in normal condition. Second, it shows that the modulator circuit is balanced. Third, it shows that the phase-shifting circuit is functioning normally. If the test does not show a normal reaction, the modulator tubes may be reversed in their sockets or new tubes tried until the trouble is localized in the tubes or circuit.

If a loud shout or whistle is directed into the microphone, the current as read at jack 2 should flicker upward when the modulators are working normally. This is because, as the modulators are brought into play, some small amplitude changes are present in the modulated output, and these register to give a meter flicker. As previously explained, this amplitude modulation is subsequently removed by the limiting action of the succeeding stages.

The condition of the tubes in all the low-power stages may readily be observed by the appropriate grid current readings. In the PA stage, however, another simple method may be used to detect tube deterioration long before replacement is necessary. In general, do not rely on tube tester readings to give the full story on whether or not a tube is suitable for service. Tube testers will commonly show a poor tube to be good, or vice versa, simply because the tube is not tested under its operating conditions in the actual set. The equipment under discussion has been designed to have an ample factor of safety, and tubes need not necessarily be replaced at the first sign of weakening. Many more hundreds of hours of service may still be left in the tubes without causing any drop in performance of the set. Furthermore, it has now been well established that there is no sound reasoning behind replacing a tube merely because it has served a certain number of hours. In the case of the 807 PA stage, tube deterioration may usually be detected long before loss of output is iminent and replacement justified.

This deterioration may be detected by operating the transmitter at normal primary voltage and detuning completely the PA tank circuit. The 807 cathode current will normally rise to 125–150 ma. with a new

tube. As the tube deteriorates, this off-resonance current will approach closer and closer the on-resonance current of 100 ma., and the dip will accordingly become less. When the off-resonance current becomes so close to the on-resonance current (say 110 ma.) that only a slight dip is observable, the RF output will start to decrease and the need of a new 807 is indicated. All these tests assume, of course, that the preceding stages have been checked and found normal.

Changing Frequency. In tuning the 25-UFM, each transformer is tuned for maximum current in the like-numbered jack. In some cases, however, there may be more than one maximum in the tuning range of the condenser, since the necessary range will permit the quadruplers to tune to other than the fourth harmonic. The transmitter tuning adjustments when made to the original frequency at the factory are marked in red, so that no mistake can normally be made in making routine adjustments. When changing to a new frequency, however, care should be taken to insure the proper selections of harmonics.

Transformer T2 is on the crystal frequency and has only one tuning point. T3 will very often show two tuning points, corresponding to the fourth and either the third or fifth harmonics. These may readily be separated by observing the position of the tuning condenser. The condensers have stops limiting their rotation to 180 degrees. In this case, maximum capacity is fully clockwise. Since the tuning range corresponds to only 30 40 megacycles, reference to the desired operating frequency will fix approximately the position of the condenser.

A number of small maximum current points can be found on T4 but the proper one will be that one giving the largest peak current when the condenser is near the position judged to be proper.

VOLTAGE CHART -25-UFM TRANSMITTER

Pin No.	V1 7C7 Osc.	V2 7A8 Mod.	V3 7A8 Mod.	V4 7C7 Quad.	V5 7C7 Quad.	V6 7C5 Doub.	V7 807 PA
1	6 0	6 0	6 0	6 0	6 0	6 0	6 0
2	260*	260*	260*	260*	260*	260*	140–250†
3	260	80	80	180	170	170	—
4	260	—	—	0	0	0	0
5	0	65	65	0	0	0	0
6	—	0	0	—	—	—	—
7	0	3	3	0	0	0	
8	0	0	0	0	0	0	0

* Plate supply measured at cold end of tank coil.

† This reading is taken with plate circuit tuned to resonance. Varies with tube and loading.

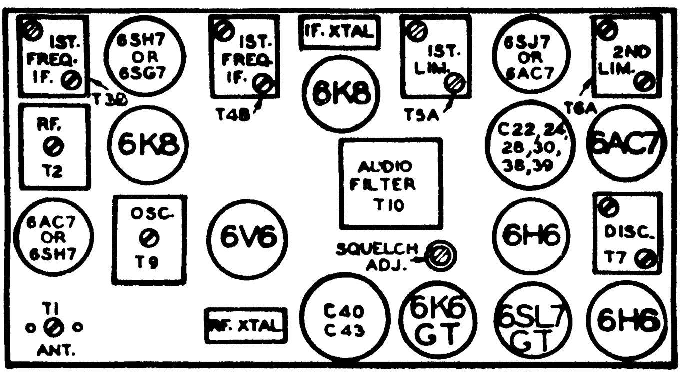
— No readings to be taken on these pins.

Plate voltage of 807 PA should be approximately that read on terminals of dynamotor. (400 v.)

20,000 ohms per volt meter used for all readings. Taken between pin and ground.

9 Tuning and Adjustment of 11-UF Receiver (Revised Model)

The receivers are carefully tuned at the factory to the specified operating frequency but should be retuned upon installation as previously indicated. Routine maintenance checks should include realignment of these same circuits. The correct settings of the transformers have been marked with red, and these markings should be used as a guide in making any adjustments. It should be noted that for these adjustments the signal source must be accurately adjusted to the proper frequency. Signal generator calibration charts are not accurate enough for this purpose. The input signal should be obtained either by direct pickup from a crystal-controlled transmitter or from a signal generator which



FM receiver (11UF) top chassis layout. (Courtesy J. M. Link.)

has been adjusted to zero beat against a crystal-controlled transmitter on the correct frequency.

The equipment needed for tuning these stages is a 0–1 ma. tuning meter, a 0–50 or 0–100 microammeter (preferably of the center zero type) a 250-volt meter, and a source of signal on the carrier frequency that can be attenuated to a low value.

The oscillator tuning may be checked by measuring the voltage between the tuning condenser shaft on T9 and ground. Tuning should be adjusted accurately for maximum voltage. With some frequency crystals, more than one voltage peak may be observed, and the factory marking of the correct setting should be used as a guide to arrive at the proper point.

The primary of the discriminator transformer (T7) is sealed at the factory and need never be readjusted. It will be found that this circuit is so band-spread and overcoupled, that there is no possible change in tuning of the primary that cannot be compensated for by readjusting the secondary.

When any of the tubes associated with the foregoing circuits are

changed, the circuits should be retuned The small variations encountered in tubes may cause a marked detuning at ultra high frequencies.

Sensitivity Check. If a signal generator whose output is calibrated in microvolts, or one whose output can be attenuated to a low level is available, the sensitivity of the receiver can be checked. When the receivers are shipped from the factory, their sensitivity is such that a signal of one microvolt or less, when applied to the antenna connector, will cause a meter reading at jack J1 of at least 15 microamperes. If a signal generator, whose output can be attenuated but which is not directly calibrated, is available, it can be checked against a new receiver. The attenuator setting for some particular tuning meter reading can be noted, and other receivers checked for sensitivity against this criterion.

Service and Test. This section will assist the service engineer in quickly localizing and remedying failures that may arise during the operation of the receiver.

Alignment of the RF and oscillator stages may be made whenever it is thought that the sensitivity of the receiver has fallen off due to detuning, but nothing is to be gained by retuning the IF transformers, since their adjustment is so broad that, once they are set at the factory, the adjustment will hold. However, should the frequency of the receiver be changed, or any of the IF transformers replaced, readjustment can be made in accordance with the following instructions.

In setting up the receiver for operation on a frequency in the 30 to 40 megacycle band other than that for which it was tuned at the factory, or if a complete realignment of the receiver is desired, a crystal of the right frequency for the new operating frequency is inserted in the crystal socket beside the 6V6 oscillator tube. The oscillator frequency is one-half the difference between the signal and the 5000-kilocycle IF frequency and the crystal is ground to one-quarter the oscillator frequency. The oscillator is adjusted by reading the voltage between the condenser shaft on T9 and ground while tuning the condenser for maximum voltage. Since sometimes more than one voltage peak may be observed, the calibration stamp on the transformer should be used as a guide to the approximate setting. The stamp reads from one to ten, and the red line on the tuning condenser shaft should be set opposite the number corresponding to the last digit of the new frequency (that is, for 38 megacycles, set at 8).

After the oscillator has been tuned, the RF transformer T2 may be adjusted. While feeding a strong signal on the new signal frequency into the antenna, insert a tuning meter into the tuning meter jack J1 and tune T2 for maximum current. This transformer is marked in the same manner as the oscillator, and the approximate setting can be arrived at in the same manner. The antenna transformer may next be adjusted for maxi-

mum current in the tuning meter. Once the approximate setting of the tuning controls is determined in this manner, the signal input is decreased until only a slight indication is obtained on the tuning meter and the adjustments on T1, T2, T3B, T4B, and T5A set carefully for maximum current in the tuning meter. The last I,F, transformer (T6A) is past the limiter grid circuit, and the tuning meter will give no indication of proper tuning in J1. To tune T6A, plug the tuning meter into J2 and proceed as previously indicated. The discriminator transformer is next adjusted by inserting a center zero microammeter into the jack marked BALANCE and adjusting the secondary of T7 for zero reading in the meter while receiving a *strong* signal. After the discriminator transformer has been balanced, the signal should be removed from the receiver and the balance meter reading noted. If this reading is not zero, the indication is that the band-pass characteristics are not accurately centered on the carrier frequency. A careful check on the tuning adjustments, using a *weak* signal, should correct the difficulty. The receiver is now in tune and only the antenna tuning need be adjusted upon installation.

Receiver Failures. The receiver normally emits a loud hiss when no carrier is being received, and the tracing of this hiss through the receiver presents a simple method of localizing failures that might occur. If the RF, mixer, and 6SH7 IF tubes are removed from their sockets, most of the loud hiss should disappear. The remaining hiss is due to the noise generated in the grid circuit of the second converter. When the 6SH7 IF amplifier is plugged in, the hiss should rise nearly to maximum level. When the first 6K8 converter is added, the hiss will increase slightly, apparently indicating that most of the noise comes from the second 6K8. This is actually not true, since the noise generated in the grid of the first 6K8 merely overrides and masks the noise previously heard. When the RF stage is added, a similar effect takes place, but no increase in hiss level is normally heard since the second limiter is already saturated with noise. It is suggested that the service engineer familiarize himself with the sound of a normal receiver by removing the first converter, then the second, and then the first IF amplifier. Then, if a failure should occur in the receiver, he will be able to localize it by the absence of the hiss.

A weak oscillator tube will result in insufficient injection to the first converter, and this in turn causes a tendency to regeneration or even oscillation in this tube. Detuning of the oscillator will cause the same condition, and therefore the oscillator tuning should be checked in routine maintenance inspection. The condition of the oscillator can be readily checked by noting the plate voltage rise measured at the oscillator tuning condenser shaft on T9. The oscillator plate voltage is dependent on the

frequency of the crystal used. The lower the crystal frequency, the lower the voltage.

The operation of the entire receiver up to the grid circuit of the first limiter may be checked by noting the tuning meter readings with a signal applied to the input. Since the tuning meter at J1 measures the grid current of the first limiter, increase of the tuning meter reading with increase in signal input indicates that the receiver is operative up to that point. Sensitivity of the receiver to that point may be measured if a calibrated source of signal is available. It should require not more than one microvolt input to the antenna to cause a 15-microampere deflection in the tuning meter. The accompanying graph may be used for an approximate idea of the first limiter grid current to be expected at various signal levels.

It will be noticed that by the use of a more sensitive tuning meter (that is, 0–50 or 0–100 microamperes) very weak signals may be more accurately judged. The meter used for balance may be used for this purpose.

The 6K8 converter tubes may vary considerably in efficiency as converters at very high frequencies, therefore a check on the sensitivity of the receiver should be made whenever one of them is changed. Tube testers offer no sure method of testing tubes for operation at high frequencies and a much more rapid and satisfactory method of determining tube deterioration is by substituting a tube known to be good in place of the suspected tube and noting the difference in receiver operation.

Weakening of the squelch tube generally manifests itself in failure of the squelch circuit to close and indicates a need to increase the setting of the squelch control in a counterclockwise direction. Here, too, the best criterion for judging the efficiency of the tube is to substitute a tube known to be good in place of the one suspected.

Other failures that may arise would be of the well-known resistor or condenser failure type that should be easily localized by the service engineer, since they manifest the same symptoms in an FM receiver as in an AM receiver. Reference to the voltage chart, circuit diagram, and parts list should simplify the solution of this type of failure.

Receiver Power Supply. The vibrator power supply Type VPA-3A has a minimum of parts, only one of which (the vibrator) is subject to wear and deterioration. Consequently, normal maintenance consists only of checking the condition of the vibrator element. Due to recent improvements in vibrator and vibrator circuit design, these power supplies provide B voltage in a very reliable manner. Vibrator failure is almost always preceded by a considerable period of decreasing output voltage. Periodic checks of the output voltage of the power supply will usually indicate

VOLTAGE CHART—11-UF RECEIVER Ed 3

Pin	RF		Conv.	IF		Conv.	Lim.		Lim.	A.F. 6SL7GT		Disc.	Sq'lch	A.F.	OSC.
No.	6AC7	6SH7	6K8	6SH7	6SG7	6K8	6SJ7	6AC7	6AC7	Off	On	6H6	6H6	6K6GT	6V6
1	0	0	0	0	0	0	0	0	0	2*	2*	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	50	±6.3	±6.3	±6.3	0
3	0	0	70	0	0	65	0	0	0	10	10			195	50–125
4	0	0	70	0	0	65	0	0	−2.5*	50	50			205	125
5	0	0	−1.6*	0	0	0	0	0	0	190	190			0	0
6	80	70	0	60	60	40	60	60	90	60	60			0	0
7	±6.3	±6.3	±6.3	±6.3	±6.3	±6.3	±6.3	±6.3	±6.3	±6.3	±6.3	0	0	0	±6.3
8	210	205	0	165	160	0	60	60	90	0	0			15	0

Power supply voltage—225 v.

Meter resistance: 25,000 ohms per volt. All readings taken on 250-volt scale except those starred which were taken on 10-volt scale.

No signal input.

First column under 6SL7GT (A.F.) is with squelch switch OFF, second with switch ON.

deterioration well in advance of failure. The 11-UF receiver will operate normally on voltages well below 200, giving ample factor of safety.

With the exception of vibrator replacement, few possibilities of failure are present. An open electrolytic filter condenser causes hum in the receiver output, while a leaky or shorted unit will cause low or no output voltage. In the latter case, the power supply fuse protects the rest of the equipment from damage. An open buffer condenser will cause low voltage or rapid deterioration of the vibrator element, while a shorted unit will again cause low or no output voltage and consequent blowing of the power supply fuse.

Ignition Noise. Before further adjustments are made, the vehicle should be examined for ignition and other electrical noises, such as charging generator brush noise. Misguided reasoning has led to a popular conception that man-made noise is completely eliminated in an FM system. It is true that the effects of noise are greatly reduced, particularly in mobile units, by the use of FM, but if the added range possibilities of FM are to be fully realized, the equipment must be given every reasonable chance to operate on the extremely small signals (compared to usual ignition noise peaks) which it is capable of using.

External noise cannot be recognized when the receiver is not receiving a carrier. In order to test for motor interference, apply (with the antenna connected) a signal just strong enough nearly to suppress the rush back-

ground noise. If the engine is then started, any interference coming from the ignition system or battery generator will immediately be apparent. Many of the new governmental vehicles are completely shielded for radio, and this shielding is usually very effective, except in the case of the generator, which sometimes needs additional attention. In most other cases, suppressors applied to the spark plugs, and a suppressor in the main high-tension lead at the distributor, will be completely effective in silencing any ignition noise. The suppressors are of the 15,000-ohm resistive type and have no appreciable effect on motor performance.

Some 0.5 mfd, condensers are included for by-passing of primary ignition coil leads and light wires in stubborn cases, but usually are not needed. It is assumed that voltage-regulated generators are supplied for maintaining the battery in condition, in view of the added battery drain imposed by the radio set. The high charging currents necessary make these units potential sources of interference. The 0.5 mfd. condensers applied to the main generator terminal will sometimes solve this problem completely. In obstinate cases, the only cure may be an RF choke in the main charging lead directly at the generator. An appropriate choke may be made by close winding 15 to 20 turns of No. 8 or larger enameled wire on a form 1 to 1½ inches in diameter. Such a choke has a DC drop of less than 0.1 volt and will not affect a voltage-regulated generator in any way.

After the receiver has been completely tuned and installed in its operating position with ignition and generator noise reduced to a practical minimum, the squelch control may be adjusted. The most sensitive position of this control is completely clockwise. With the adjustment in this position, and the squelch switch on, advance the volume control and observe the output of the receiver with no-signal input. Increase the position of the squelch adjustment in a counterclockwise direction until the output of the receiver is entirely silent. This adjustment will hold for most noise conditions, no matter how severe, as a result of the special circuits incorporated in the design of the 11-UF. Note that in its most sensitive position the squelch sensitivity is between 0.1 and 0.2 microvolt and that this adjustment will prove sufficient in most cases even where the normal noise level is high.

10 Operating FM Mobile Equipment

The following instructions will be helpful in operating FM mobile equipment.

To Start Equipment from Completely Off Condition. Turn on the volume control in clockwise position. This snaps on the filament-vibrator circuit power at the very beginning of the clockwise rotation. The remainder of the rotation is entirely volume control. When this switch is

snapped on, within thirty to fourty seconds the receiver comes on full operation, while the transmitter tubes heat up ready to use on occasion. A green indicator light comes on in the control unit.

To Transmit. Depress the switch push button on the microphone handle and speak into the microphone transmitter portion. When the push button is depressed, the red indicator light comes on in the control unit. At the same time, the dynamotor starts in the transmitter unit (rear trunk); the antenna transfers from receiver to transmitter by means of a relay; and the receiver becomes inoperative.

To Cease Transmitting and Resume Reception. Release the switch push button on the microphone handle. The red light goes out; the dynamotor stops, the antenna relay releases the antenna from transmit contracts to receive standby contacts.

Use of Squelch. The squelch control in the receiver unit is ordinarily present, so that the loudspeaker will not register any signal or noise below a certain level. It is adjusted so that this level is higher than any objectionable noise, but lower than the signal from the transmitting station. The result is that noise-free conditions prevail at the receiving point. When transmission occurs, it is strong enough to override interference and the squelch. The use of the squelch means a reduction in maximum communication range. For that reason, there is a squelch switch on the control unit to cut it out when a station is too far or too weak otherwise. At such times, the necessity for communication justifies bringing in noise and interference, as the latter is not total, and communication can still be possible for many miles. In practice, up to 50 per cent more range can be obtained by keeping the squelch off. When the squelch is off, a constant hiss is heard, similar to a regenerative receiver, which does not disappear until a signal comes in. It then is completely overridden or is reduced to a negligible level.

The volume control does not affect the range. It affects only the signal strength locally at the loudspeaker. It is in the audio-frequency rather than the radio-frequency section of the receiver. The squelch control does affect the range on weak signals. It should be turned up as far as the background noise permits.

The French-type handset contains microphone, earpiece, and press-to-talk button. Signals can be heard from the loudspeaker or the earpiece, or from both.

CHAPTER NINE

INDUCTION RADIO AND GUIDED CARRIER SYSTEMS

1 Carrier Current Communication

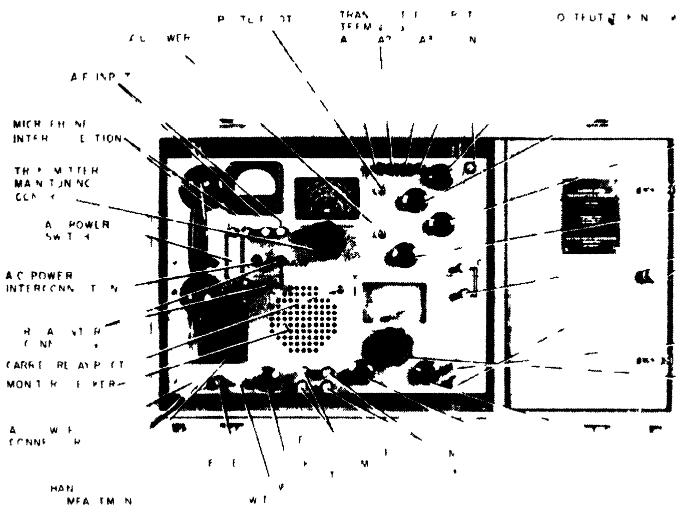
Carrier current systems provide means of establishing two-way voice communications over wire circuits, as well as the transmission and reception of control signals. This is possible by the use of high-frequency signal energy impressed on existing power lines, telephone circuits, or other metallic conductors that may be extending between communicating points.

These systems, together with modified carrier systems, have been extensively applied by public utility companies, railroads, and telephone and telegraph companies for several years. They are known by various names such as: (1) carrier current, (2) wired wireless, (3) induction communication, and (4) induction radio. These designations are to some extent synonymous and do not necessarily represent different types of communication. The name used, in part, varies with the application and the particular communication technique that is utilized

When the equivalent of a radio transmitter and a receiver are physically connected to a power line by capacitive coupling, it may be called carrier current or wired wireless.

If a method such as the Union Switch and Signal System is employed, whereby the high-frequency current is applied directly to the railroad trackage during transmission, while picked up inductively from the track and wayside wires during reception, it may be called an induction or inductive system.

If a method such as that used by the Halstead Traffic Communications Corporation is employed, whereby transmitters and receivers are not capacitively or conductively coupled to metallic conductors but,



Front view of induction radio transmitter and receiver. (Courtesy Halstead Traffic Communications Corp.)

instead, the short gaps of distance between wayside conductors and mobile vehicles, such as automobiles and railroad trains, are bridged by means of the combined induction and radiation fields surrounding wayside wires or loop radiators, it is known as induction radio.

Actually, all of these methods utilize carrier techniques or derivations therefrom, because in each case they rely on existing or specially provided wires or other metallic conductors to carry an impressed high-frequency signal, having a definite frequency or wave length, from one point to another without more than very limited local radiation in space.

Shortly after World War I, the U.S. Army Signal Corps and leading landline communication companies increased the efficiency of landlines by utilizing radio principles, and thus justified the high cost of maintaining long landlines. Instead of transmitting one telegraph or telephone message over a single wire, they applied many radio-frequency channels, being limited only by the available useful carrier channels in the radio-frequency spectrum. Today, it is not uncommon for one wire to handle forty or more channels of communication by transmitting and receiving at each end on different wave lengths or frequencies, with little radiation in space and maximum transmission along the wire itself for its entire length.

Carrier signals are usually impressed on wire circuits through coupling networks in which series capacitors of high-voltage rating are utilized. In many cases, tuned inductance/capacitance (L/C) networks are used

in order to transfer the maximum amount of high-frequency power from a transmitting equipment to the wire circuits.

At receiving points, suitable couplings are also utilized, connections ordinarily being made through series capacitors between wire circuits and the input circuit of the receiver

Frequencies employed in carrier systems are usually below 200 kilocycles, although much higher frequencies have been utilized. In the majority of cases, frequencies between 50 and 200 kilocycles are employed The lowest frequency used by carrier systems described in this book is 5.7 kilocycles, developed by the Union Switch and Signal Company for certain railroad operations. The highest frequencies are employed in induction radio circuits, such as those of the Halstead highway radio system used on the George Washington Bridge, New York City, during the World's Fair, operating on broadcast frequencies above 500 kilocycles to enable motorists to use standard broadcast receivers to receive the transmissions.

Frequencies above 2000 kilocycles have been used in some instances, but, in general, the lower frequencies are preferred because of the reduced attenuation per unit length of line as the carrier frequency is decreased.

Firms such as the Communication Equipment and Engineering Company have installed many carrier systems on railroad and power company wire circuits for both telephony and telegraphy, whereby several channels of communication are possible on a single circuit. A typical circuit is on the Burlington Railroad from Chicago to Denver.

2 Induction Radio

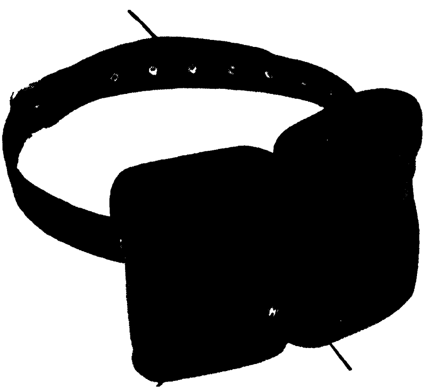
While similar in many respects to conventional carrier current systems, induction radio systems have an important distinction in that physical connections between the equipment and wire circuits are not used in many cases. This eliminates objectionable line-coupling features which may involve installation complications, with possibility of accidental shorting of high-voltage power lines or other wire circuits and consequent inoperation or damage to the circuits.

Induction radio signals are transferred to wayside wires or other metallic conductors employed as guiding media by means of the laterally extending induction and radiation fields surrounding loop radiators or wire transmission lines upon which radio-frequency signal energy is impressed. No direct connections with wire lines are necessary. The wire circuits merely serve as a transmission medium in the sense that the ether serves as a transmission medium for space radio waves. It makes possible and feasible long-distance two-way communication between a fixed point and mobile units, proceeding within the localized signaling

zone which extends in the vicinity of overhead wire circuits, in many cases for distances of several hundred miles.

If suitable automatic repeating equipment is employed at wayside points along highways or railroad right-of-ways, effective two-way communication may be maintained between mobile units 50 to 100 miles apart.

In induction radio signaling circuits, the combined induction and radiation fields are restricted within a short lateral distance from wayside wire circuits, but may extend in a longitudinal direction as far as the wayside wires run along a highway or railway, repeaters being employed at intervals of 75 to 100 miles, or wherever necessary. Since induction radio systems are effective at frequencies up to several hundred kilocycles, and even higher in some cases, frequency modulation techniques may be advantageously utilized. The employment of FM has been found to be desirable, especially for railroad and highway communications, where high electrical noise levels are commonly experienced due to electrical devices on motor vehicles, locomotives, or as encountered at wayside points.



Induction radio receiver with built-in belt-type loop antenna. Designed by Halstead Traffic Communications for personalized applications.

Frequency modulation is also preferable in systems where several mobile units are employed, as less interference between signals from the different units results. As in FM systems, which operate at higher radio frequencies and are dependent on the radiation field, an induction radio receiver responds principally to the strongest signal. Greater freedom from heterodyning effects, or squeals, between a number of mobile units operating simultaneously in a communication network is obtained when FM circuits are employed instead of AM. This holds true even though the deviation ratio on the lower radio frequencies must of necessity be much smaller than on the higher radio frequencies used for conventional space radio communication, where more frequency spectrum is available.

3 FCC Requirements and Frequency Selection

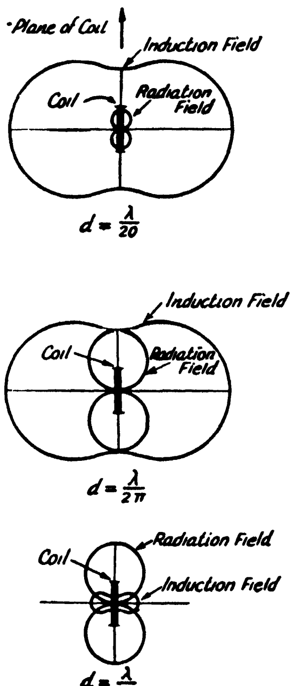
The Federal Communications Commission recognizes two kinds of fields as being associated with electromagnetic waves employed in radio communication. It defines one as the induction field and the other as the radiation field.

The conventional technique for effecting two-way radio communication through space is to employ the higher radio frequencies in order to develop a maximum radiation field from an antenna correctly cut or matched for the operating wave length. This is accomplished in the simplest and most efficient manner on the highest frequencies, or shortest wave lengths.

On the other hand, it is found that by employing the lowest radio frequencies, or longest wave lengths, the same amount of power develops a maximum induction field and minimum radiation field, thereby making possible an entirely different but highly useful communication technique. For example, a closed-circuit loop inductor can be substituted for a conventional open-end antenna and thus produce a strong induction field with relatively little radiation field. This process involves the use of a varying current in an inductance with consequent production of a magnetic field around the turns. The induction field is strong in the immediate vicinity of the loop, and decays with the cube of the distance, while the radiation field decays with the square of the distance. The induction field, when of sufficient intensity, is able to induce carrier signal energy on any wayside wires, whether they be power lines, telephone or telegraph wires, or special wire provided for that purpose. The induced carrier signals have the same frequency or wave length as the initial signals from the transmitter. This radio-frequency carrier signal will travel along the wire or wires, even where some of them end or others come into the circuit, with sufficient intensity and efficiency to be picked up by induction radio receiving equipment tuned to the operating frequency. Since the transmitting and receiving points on highways or railway tracks are seldom far removed from wayside wires, the induction field is sufficiently strong to make possible useful communication in a longitudinal direction along traffic lanes for distances that can exceed 100 miles under favorable conditions for either fixed or mobile stations.

The induction field obeys the usual magnetic laws. It is strongest in a direction perpendicular to the plane of the loop. The loop on the mobile unit therefore is usually mounted in a plane parallel to the wayside wires. This makes possible the greatest concentration of lines of force at the wayside wires, thereby inducing maximum signal voltage on these conductors. The carrier signals, once impressed on the wayside wire circuits, travel with varying degrees of attenuation throughout their length. They are useful for two-way communication until a point is reached where the signal energy is attenuated to a level where the signal-to-noise ratio has become unfavorable. If further communicating range is required, the signals are boosted and repeated by an automatic repeater station installed in association with the wire circuits at a point where the signal-to-noise ratio begins to drop to a low value.

As induction radio fields are most effective at low frequencies, because a signal of maximum strength can be produced with least possibility of interference with other induction or radio communication services that are not in the immediate proximity of a given wayside wire circuit, these fields are produced with very low transmitting power, usually ranging from 3 to 25 watts. With such low power and the absence of antenna which might be effective as radiators at the long wave length such low frequencies represent, there is relatively little likelihood that the signals would be picked up above the existing noise levels by any radio receiver located at points remote from the wayside wires. In practice, the space radiation is so negligible when an induction radio system is properly installed that the Federal Communications Commission permits operation at the lower radio frequencies of equipment without federal licensing, providing that regulations of the FCC with respect to low-power radiofrequency devices are complied with.



The relationship between induction and radiation fields about a coil or loop antenna at various distances is shown here. Below each diagram the distance in terms of wave length is indicated. At a point very near the coil $\left(\frac{\lambda}{20}\right)$ the induction field strongly predominates. At the distance $\frac{\lambda}{2\pi}$ (center) the two are equal in the plane of the loop. When the distance is a full half-wave (bottom) the radiation field is the stronger.

An excerpt from Part 2 of the General Rules and Regulations of the Federal Communications Commission, effective since June 15, 1939, with respect to induction field communication follows:

Provisions Governing the Operation of Certain Low-power Radio-frequency Devices

Sec. 2.101. *General.* Pending the acquiring of more complete information regarding the character and effects of the radiation involved, the following provisions shall govern the operation of the low-power radio-frequency electrical devices hereinafter described.

Sec. 2.102. *Apparatus Excepted from Requirements of Other Rules.* With respect to any apparatus which generates a radio-frequency electromagnetic field functionally utilizing a small part of such field in the operation of associated apparatus not physically connected thereto and at a distance not greater than

$\frac{157{,}000}{\text{f. (kc.)}}$ ft. $\left[\frac{\lambda}{2\pi}\right]$ the existing rules and regulations of the Commission shall not be applicable, provided:

(a) That such apparatus shall be operated with the minimum power possible to accomplish the desired purpose.

(b) That the best engineering principles shall be utilized in the generation of radio-frequency currents so as to guard against interference to established radio services, particularly on the fundamental and harmonic frequencies.

(c) That in any event the total electromagnetic field produced at any point a distance of $\frac{157{,}000}{\text{f. (kc.)}}$ ft. $\left[\frac{\lambda}{2\pi}\right]$ from the apparatus shall not exceed 15 microvolts per meter.

(d) That the apparatus shall conform to such engineering standards as may from time to time be promulgated by the Commission.

Sec. 2.103, *Exceptions; Interference to Radio Reception.* The provisions of Sections 2.101 and 2.102 shall not be construed to apply to any apparatus which causes interference to radio reception.

Sec. 2.104. *Inspection and Test; Certificates.* Upon request, the Commission will inspect and test any apparatus described in Sections 2.101 and 2.102, and on the basis of such inspection and test, formulate and publish findings as to whether such apparatus does or does not comply with the above conditions, and issue a certificate specifying conditions of operation to the party making such request.

How Radiation and Induction Fields Are Created*

It may help in understanding the distinction between the two kinds of fields to review the phenomenon of radiation, as far as that can be reduced to simple, nonmathematical concepts. First of all, consider a simple coil with DC flowing through it. A magnetic field is set up around the coil, extending into space for a certain distance with a strength depending on the magnitude of the current. This field has a certain polarity, depending on the direction of current flow.

Now suppose the current is instantaneously cut off. The field collapses and the energy in it returns to the coil. But if, the very instant the current stops flowing in one direction, it starts flowing again in the opposite direction with equal magnitude, an equal and opposite electric field will be set up before the original field can return to the coil. Unable to return home because the new field has forced it out, the original field sets forth on a journey through space.

That constitutes radiation—the successive detachment of one electrical field after another in a series of waves as each is succeeded by another with each reversal of current. In an ideal system with instantaneous reversals, all of the energy in each field would be radiated, and none would return to the coil. In actuality, each succeeding cycle from the AC generator feeding the coil represents a slow rise and fall of potential. This gradual building up to peak amplitude and corresponding gradual decay allows time for some of the energy to return to the coil before the new field becomes strong enough to send it away. The slower the rise and fall—that is, the lower the frequency—the more of the initial energy returns to the coil. Thus at audio or very low radio frequency most of the energy

* Courtesy American Radio Relay League, from "The Induction Field Is the Field that Stays at Home," "QST," April, 1942, by Clinton B. DeSoto.

succeeds in returning and very little is radiated. At the higher radio frequencies, on the other hand, the cycles come along so fast that the electric field—even though it travels 186,000 miles per second--has little time in which to go out and return, and as a result most of it gets detached and is radiated into space.

The part of the field that returns to the coil is the induction field, while the part that is detached is called the radiation field.

The most obvious difference between the radiation and the induction fields is that the radiation field is the weaker near the antenna and the stronger at a distance. This is illustrated in the accompanying diagram, based on studies made by Professor Ramsey, which shows the relative strength of the two fields at various distances identified in terms of the operating wave length. Specifically, the radiation field varies inversely as the distance, while the induction field from a coil varies inversely as the cube of the distance. The two fields are always equal at a distance equal to the velocity of light divided by the angular velocity.

This expression will be recognized as that used in the FCC rule to state the maximum distance at which the measured field may not exceed 15 μv. per meter, to ensure that no interference is caused radio services. Actually, since the two fields are in time quadrature this measured value represents 1.414 times the true value of either field alone, but as far as the receiving antenna or coil is concerned it has no social prejudices and responds to both fields as one.

Thus we have our first design rule —the measured field strength at the distance

$$\frac{\lambda}{2\pi} \text{ meters or } \frac{157{,}000}{f_{kc}} \text{ ft. or } \frac{30}{f_{kc}} \text{ miles}$$

must not exceed 15 μv. per meter.

The tables shown on page 151 represent maximum distance permitted by the Federal Communications Commission, at which the field strength must not exceed 15 microvolts per meter.

The distances in the above tables are those beyond which the total field strength must have attenuated to a value less than 15 microvolts per meter. The induction signaling distance on the lower frequencies is greater than on the higher frequencies because the point at which the induction and radiation fields become of equal intensity, as noise levels on such frequencies ordinarily do, is expressed by lambda divided by 2 pi, defined above. The value of 15 microvolts per meter is arbitrary, usually representing a signal level which on the lower frequencies is at or near the threshold between noise and signal.

For example, the spacing between a vehicle (such as an automobile or a locomotive) and the wayside wires might be a distance of 50 feet. If an operating frequency of 10 kilocycles is used, there can be a very strong signaling field at the wayside wires and still be a signal of less than 15 microvolts per meter at 15,700 feet. As the frequency is increased, a correspondingly weaker signaling field must be used to induce a signal voltage on the wayside wires, so as not to exceed 15 microvolts per meter at a distance in feet equal to 157,000 divided by the frequency in kilocycles.

EXAMPLES OF THE LAMBDA 2 PI FORMULA CONVERTED TO FEET

Very Low Frequency Kilocycles	Distance Feet	Low Frequency Kilocycles	Distance Feet
1	157,000	10	15,700
2	78,500	20	7,850
3	52,333	30	5,233
4	39,250	40	3,925
5	31,400	50	3,140
6	26,166	60	2,616
7	22,428	70	2,242
8	19,625	80	1,962
9	17,444	90	1,744
10	15,700	100	1,570
Medium Frequency Kilocycles	Distance Feet	High Frequency Megacycles	Distance Feet
100	1570	1	157
200	785	2	78.5
300	523	3	52.3
400	392	4	39.2
500	314	5	31.4
600	261	6	26.1
700	224	7	22.4
800	196	8	19.6
900	174	9	17.4
1000	157	10	15.7
Very High Frequency Megacycles	Distance Feet	Ultra High Frequency Megacycles	Distance Feet
10	15.7	100	1.57
20	7.85	200	.785
30	5.23	300	.523
40	3.92	400	.392
50	3.14	500	.314
60	2.61	600	.261
70	2.24	700	.224
80	1.96	800	.196
90	1.74	900	174
100	1.57	1000	.157

Note: To compute for frequencies and distances in feet other than given in the table above, use the following formulas:

$$\text{Distance in feet} = \frac{157{,}000}{\text{Frequency in kilocycles}}$$

(Change 157,000 to 157,000,000 if divided by frequency in cycles per second. Change 157,000 to 157 if divided by frequency in megacycles).

$$\text{Frequency in kilocycles} = 157{,}000 \times \text{Distance in feet.}$$

$$\text{Distance in meters} = \frac{\text{Wave length in meters}}{6{,}2832}$$

$$\text{Wave length in meters} = \text{Distance in meters} \times 6.2832.$$

Induction radio techniques employ loop radiators instead of the open-end antenna systems used in conventional space radio communication. Induction radio systems therefore can provide useful communication only over the limited distances covered by the induction field in the

vicinity of loop radiators or wayside wires. To have an adequate signal fed to the receiver by the pickup loop at the receiving point, it is necessary to develop a strong field at the transmitting point. Usually a signal having a level of several hundred millivolts (that is, several hundred thousand microvolts) is actually impressed on the wayside wires. At a fixed point, this can be done with less than 10 watts of power since the inductor cable is located close to the wayside wires. At the mobile station, the power must be increased to as much as 50 watts or more because the field developed by the relatively small loop radiator is much less than the extended field surrounding the induction cable, while the distance between the loop and wayside wires is greater. The amount of power usually depends on the circumstances and conditions prevailing with respect to the location of wayside wires, their type, number, length, and other factors, such as quality of insulators and continuity of circuits.

In general, a low frequency is used in order that the distances given in the tabulations may represent many times the distance between the loop on the mobile vehicle and the wayside wires. It is then possible to have an effective signal at the receiving point while still not exceeding 15 microvolts per meter at a distance in feet of 157,000 divided by the frequency in kilocycles.

It is understood that the Federal Communications Commission will permit field strengths to exceed 15 microvolts per meter at lambda divided by 2 pi distances, if under some circumstances, as in rural or isolated areas or where noise levels are excessively high, there is no resultant interference to licensed radio services.

From the tabulation, it therefore can be seen that as frequencies extend above 1000 kilocycles, the permissible nonwire communication range becomes unsatisfactory, becoming less than 150 feet. If less signal strength or short distance gaps between signaling equipment and wires are permissible, particularly with FM type of equipment, the use of frequencies up to 3000 kilocycles may be feasible in some cases. It would then require that signals be impressed on wayside wires by a transmitting source located very close to the wires, so that a fairly strong carrier signal can be impressed on the wayside wires without causing too strong a field at the distance in feet of 157,000 divided by the frequency in kilocycles.

Because of the relatively greater attenuation (that is, loss in signal strength) of carrier signal energy on telephone and telegraph lines as compared with the high-tension power lines of the public utilities, lower frequencies are usually employed in connection with the telephone and telegraph circuits.

The selection of the most suitable frequency is of great importance. Interference may be encountered when establishing an induction radio

system, which, in some instances, will require a change in the operating frequency of transmitters and receivers of the communication network. Services with which interference may be caused are:

1. Carrier communication channels and control circuits already in use by power companies or railroads along the highway or railroad right-of-way.
2. Carrier telephone circuits of telephone companies.
3. Carrier telegraph circuits of telegraph companies.
4. Radio listeners on common listening frequencies or on IF (intermediate frequency) where superheterodyne receivers are employed.

Frequencies higher than about 200 kilocycles should not be used, because the possibility of radiation is greater and there is more likelihood of interference to radio services; for example, many radio receivers have intermediate frequencies in superheterodyne receivers, such as 175, 262, or 455 kilocycles. There should also be sufficient frequency separation to prevent creating interference. A spacing of about 20 kilocycles from such frequencies should ordinarily be sufficient. Interference to an IF frequency cannot be tuned out by the radio listener as it comes in with about equal intensity all over the dial. It is a condition distinct and apart from the other circuits in a receiver which can be tuned or changed in frequency to pick up various stations singly.

By using low-frequency low-power equipment, such as the 10-watt transmitter common to induction radio systems, the likelihood of space radiation with resultant interference to radio listeners is very small. Harmonic interference must also be avoided by not choosing a frequency which, when multiplied by some number, corresponds to the exact frequency used by radio stations in the area.

While greater signal energy can be impressed on wayside wires at a lower frequency than on a higher frequency without exceeding 15 microvolts per meter at the specified distance, this is offset in part by the increased noise level on lower frequencies, such as static or man-made interference. Also on low frequencies, the total frequency spectrum is relatively limited with respect to available channels, which makes it difficult to provide frequency modulation. FM requires more frequency space, since it operates by changes in carrier frequency with impressed voice signals, as compared with changes in amplitude when a voice signal is impressed on an amplitude-modulated transmitter.

While less signal energy can be impressed on wayside wires at higher frequencies, this, in turn, is offset partially by the reduced noise level on the higher frequencies. This makes possible a better signal-to-noise ratio, so that a weaker signal can be heard effectively at a receiving point by using greater amplification. It also simplifies the use of frequency

modulation with greater deviation ratios. This further reduces interference or static and increases the effective signal strength at receiving points.

In establishing an induction radio system for the first time, it is necessary for the planning engineers to consult with the telephone, telegraph, and public utility companies in the area to determine what frequencies are being employed in existing carrier current circuits; also, to determine what circuits are contemplated for future use or before the proposed system will be completed. In the event of subsequent interference or channel-occupancy conflict between two or more services, the accepted procedure is that the initial service has the priority rights. An exception might be where the initial service is not using or is making inadequate use of several frequencies, tying them up for selfish reasons or to meet eventualities that may not materialize. In any case, the new service should be installed on a co-operative basis, and the operators of existing services should be informed of the new system and its frequency requirements to minimize the possibility of interference with existing circuits.

In general, there should be little or no conflict between services employing induction radio and those employing conventional space radiation systems. The frequencies best suited for the former are usually least satisfactory for the latter, and vice versa. The different systems have multiplied the number of suitable communication channels, and all are useful. Each is superior or inferior to the others in many ways, the extent determining where or how each should be utilized.

Induction radio systems appear to be superior to conventional space radio communication methods on traffic lanes where long distances are involved; where considerable range is desired; where wayside wires exist; and in industrial and terminal areas where restricted transmitting range is desired. The induction method is also advantageous in mountainous or urban sections where curves, hills, or steel structures may make difficult the use of high-frequency space systems; also, where the station and operator license requirements of the Federal Communications Commission are difficult to comply with.

Conventional space radio systems are superior on high frequencies when increased channel space is required; where wayside wires are nonexistent, buried, or enclosed in a metallic sheath; where wayside wires are too far away from the highway, railway track, or other traffic lane; where wires are down or destroyed over wide areas; where all suitable frequencies for induction radio communication are completely occupied; and where very high frequencies or microwaves must be resorted to.

Each has its place in the field of two-way communication, so much so that extremely essential services such as railroads might be justified in providing both facilities on moving trains to assure continuity and de-

pendability of operation under all the conditions encountered in an extended zone of operation.

4 Utilization of Wayside Wires

As induction radio systems utilize high-frequency carrier signals on existing wire circuits, the degree of attenuation of signal energy is directly related to the length of line circuits. The amount of attenuation also depends on the type and size of wire conductors employed; the type and size of insulators used to support the conductors and prevent leakage to ground or other circuits; and the amount of moisture or other conducting or semiconducting material deposited on the insulators.

High-tension power lines usually employ heavy copper wires of large cross section. In addition they use large insulators having excellent insulating surfaces of considerable area. As a result, a much better conducting path for radio-frequency signal energy is provided than might be realized from a much greater number of small copper, steel, or iron telephone or telegraph wires mounted on small insulators. This is particularly true where the smaller insulators have accumulations of moisture and soot, which may cause appreciable leakage.

While it is much easier to achieve maximum communication ranges along an entire line if the wires are extended as a continuous line without interruption at various points, satisfactory communication over desired ranges can usually be realized when much less favorable conditions prevail. Although carrier signals are attenuated by line transformers, sufficient signal energy usually remains to effect good communications for substantial distances. For example, if there are several parallel wires at the transmitting point, and it is desired to communicate 25 miles, with no complete continuity of any one of those wires existing for the entire distance, each of the wires is surrounded by a radio-frequency induction field which extends along the entire length of the wire, gradually becoming weaker with distance. If one or more pair of wires are terminated or are interrupted in any way, such as by a transformer or by a user of telephone or electric light service, the remaining wires still carry the induction field onward. The initial field carried on by the remaining wires induces signal energy in any new wires it encounters along the circuit. The new wires in turn take over and repeat the process. This continues until the reduction in signal strength has reached a point where the signal-to-noise ratio is low and communication becomes unsatisfactory.

The longitudinal communication range that may be obtained with respect to extended electric power or telephone lines is largely determined by the following factors:

1. Strength of the signal as impressed on the line at the initiating point. This depends on the power of the transmitter at the initiating point; the coupling method employed to transfer signal energy from the transmitter to the wayside line or lines: and the disposition of loops on mobile units or induction cables at wayside stations.

2. Degree of attenuation per unit length of line. This is dependent on the transmission characteristics of the line, including quality of insulation of the line at the operating frequency.

3. Number of interruptions in the line or lines.

4. Number of shunting loads on the line or lines.

5. Electrical noise levels on lines and in proximity to tne wire circuits. The signal must override electrical noise in order to provide intelligibility at receiving points. Electrical noise levels are high at low frequencies, especially during periods of severe static, as in local thunderstorms, and when electrical devices with excessive contact arcing are employed. There will be least noise if FM is employed, especially if a good deviation ratio is utilized.

While it is of course preferable not to have any of the unfavorable conditions mentioned above, engineers should plan to cope with existing line circuits rather than to attempt to make extensive changes in them. Provision should be made to take care of excessive line noise by impressing sufficient energy at the transmitting point to provide good signal-to-noise ratios. If longer communication ranges are required than the conditions otherwise permit, automatic repeaters may be used where necessary to maintain high signal levels without the excessive space radiation that extremely high transmitter power might create.

At receiving points, a receiver of sufficient sensitivity and selectivity should always be employed so that received signals will have sufficient volume and intelligibility to meet all conditions of operation. In most instances, the unfavorable conditions indicated above quickly become apparent at receiving locations, are fairly constant, and usually can be compensated for at the time the system is established. Later, if a system is found to be overpowered, there is no problem in reducing the power output of transmitters to the desired value.

In induction radio systems developed by the Halstead Traffic Communications Corporation for governmental activities, regulation of power is facilitated by use of an RF attenuator in the output of the transmitter. This permits use of a single control switch to regulate the amount of power impressed on wire circuits without changing the output loading of the transmitter.

Simple carrier telephone systems for communicating between two or more fixed points—, for example, interoffice service over power lines—need do little more than couple their transmitting and receiving equipment to the power lines by means of coupling condensers of sufficient high-voltage ratings to withstand safety normal line voltage. Such cou-

pling condensers are of low capacity in order to pass RF signal energy without draining power from the line. This provides the necessary isolation against direct shorts or possibility of undesirable current drain from the power lines. The power line is unaffected so far as its primary purpose is concerned.

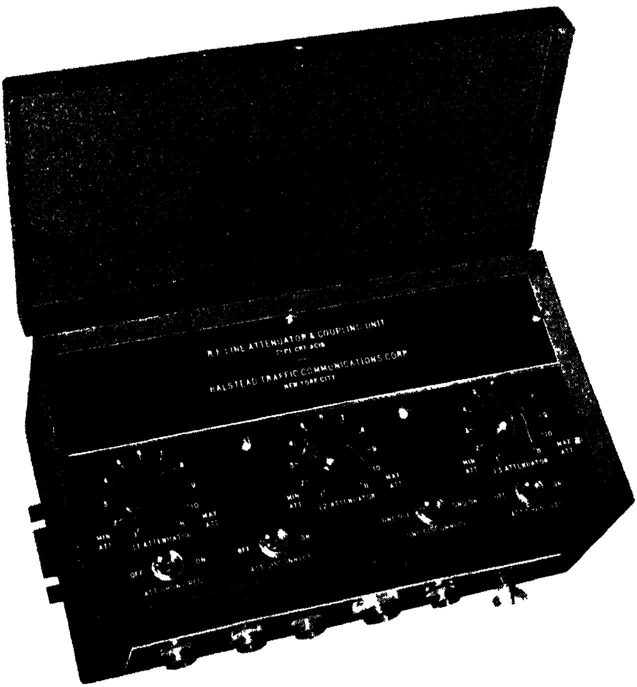
Nevertheless, it is able in most cases, to serve as an excellent transmission medium for radio-frequency signal energy. This is possible because of the great difference in frequency between the electric current flowing in the electric power circuits and the signal energy of the carrier circuits. For example, the line may be designed to handle high-voltage electric power at a frequency of 60 cycles per second. The line also may serve as a transmission medium for radio frequencies between 10,000 cycles and 3,000,000 cycles per second (corresponding to 10 kilocycles and 3000 kilocycles), or even higher, without difficulty. The coupling condensers are normally of such small capacity that they will readily pass the high radio frequencies but will effectively block the passage of very low frequencies, such as 60 cycles, employed by the electric power circuits.

As a safeguard, fuses, overload relays, or other devices are generally used to provide protection in the event that the coupling capacitors should become shorted or grounded and form a path for 60-cycle electric power to flow through the carrier equipment to ground. Shorting or grounding out of the coupling capacitors would result in damage to the equipment, or fire might occur, if these safeguarding features did not exist to protect the equipment against such contingency.

In the case of induction radio systems, in which no coupling condensers may be used and signals are inductively impressed on wire circuits without any physical connections between transmitter and wayside wires, an added safety factor is provided. Such inductively coupled systems require no connection of any type to the power lines or other types of wayside wires. In this case, however, the lines preferably should be of the open-wire type, as ordinarily exist in overhead installations of power, telephone, and telegraph lines normally extending along highways and railroads.

In the Halstead induction radio systems, special radio-frequency coupling lines or induction cables are often employed to effect transfer of energy to or from such wayside wires. These special lines or induction cables normally extend parallel to the wayside wire circuits and in close proximity thereto for distances of 500 to 1000 feet. In actual practice, the coupling line is installed on existing telephone or electric power-line poles at a distance of several feet below the existing wire circuits. In some instances, the coupling line is formed as a loop; in others, the far end of

the line is connected to ground through a termination unit. This termination unit comprises a matching network of inductance, capacitance, and resistance, with variable controls being provided to match the surge impedance of the coupling line, thereby reducing the amount of wave reflection and consequent radiation of radio wave energy from the line. Arrangements of this type permit the establishment of a concentrated induction field of relatively great intensity to exist throughout the length



R.F. line attenuator and coupling unit. (Courtesy Halstead Traffic Communications Corp.)

of the coupling line, with the result that ample signal energy is induced on wayside wire conductors.

As this signal energy is induced on all the wayside wires supported by the poles on which the coupling line is supported, and since the induced signal voltage in all the wires is in phase, relatively little counterelectromotive force exists on different wire circuits at the coupling point. Inductive coupling methods, as used in the Halstead systems, have many practical advantages. They facilitate the transfer of signal energy from wayside transmitting equipment to any wayside wire circuit, regardless of the normal voltage of the circuits and the different impedances of the

various circuits. As a result, no specially trained installation personnel or expensive high-voltage coupling and matching networks are required to impress signals on high-tension power lines effectively and safely. Such induction coupling methods also provide better protection against lightning in the event it should strike the lines, as no physical or directly connected conducting circuits are provided between the transmitting/receiving equipment and the wayside wires. The use of the induction cable coupling method also possesses an advantage in that a standard transmission line or coupling circuit of known impedance may be employed. The output circuit of the transmitter may then be designed to feed most effectively into the definite load presented by the induction cable circuit. As commercial power lines and telephone and telegraph wires have varying impedances, with rapid changes in loading at various times, it would be difficult for field engineers to match correctly the impedance of these wire circuits except for short periods of time.

Signals from mobile units are likewise impressed inductively on wayside wire circuits through utilization of a loop antenna of suitable dimensions. This is installed on the mobile unit and usually extends in a plane parallel to the wire circuits, orientation being such that maximum coupling is obtained.

In some cases, induction radio methods employ small coupling capacitors at fixed points in connection with low-voltage wire circuits. Signal energy is then transferred by these low-voltage wire circuits to parallel high-tension wire circuits where these are present. This method has a disadvantage in that improper matching may result at coupling points, with consequent reduction in the amount of signal energy impressed on the wire circuit, improper loading of the transmitter, and likelihood of excessive harmonic emission.

Induction radio systems are usually set up and adjusted in connection with a field-strength meter located in a lateral direction at right angles to the line with respect to existing wayside wires. This is done at a distance of several hundred feet from the wayside wires and approximately one mile from the transmitter coupling point. The transmitter and its associated attenuator, or other output-power regulating control, are then adjusted to provide maximum signal intensity at the measuring point, Subsequently the field-strength meter is placed at a distance from the induction cable of 157,000 feet divided by the frequency in kilocycles. Measurements are then taken to determine to what extent the signal level must be reduced, if necessary, to meet the existing regulations of the Federal Communications Commission.

Induction radio systems require elevated wires such as those which normally exist along railroads and highways. In zones where wayside

wires are buried, or are located at distances of several thousand feet from traffic lanes, or are covered in lead sheathing, or are nonexistent, induction radio signaling ordinarily is ineffective. It then becomes necessary to install an overhead wire or other suitable transmission line to form a bridge between points where overhead wires are present. Instead of an overhead wire, it may be advisable in some instances, as in airport installations of the Halstead system, to install a suitable RF transmission line in a nonmetallic protective conduit or other covering, which may be located on or in the ground along railroad trackage or at the edge of highways. In some cases, as in the Halstead highway radio system, a line of this type may be located between two highway lanes of a parkway. On railroads, this line may be installed between sets of railroad tracks, thereby reducing the lateral distance between the mobile station and the wayside wires.

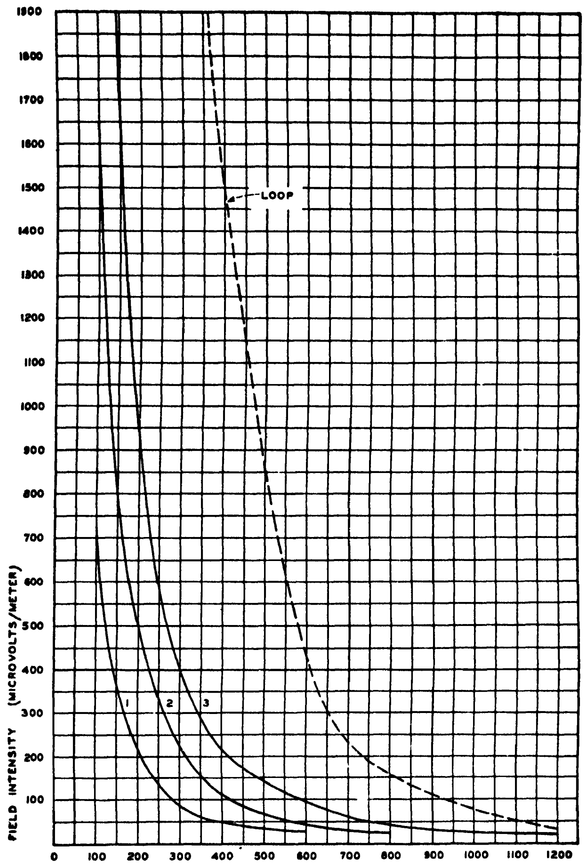
If and when power lines are extensively placed underground, and telephone wires are replaced by a buried coaxial cable employing a high-frequency carrier, it is justifiable and feasible to provide a special RF transmission line along lanes of traffic specifically for induction radio communication. This is actually employed in one form of the Halstead system. It would not be too costly or difficult to provide and would unquestionably add to the over-all utility of induction radio systems. Such a line could then be of ideal conducting properties and be continuous in length and free from any interruptions or appendages tending to reduce performance. Since there would then be no other carrier frequencies of a comparable nature in use on wayside wires, a maximum number of clear channels would be provided. Appreciable ranges would then be possible with low-power equipment, and excellent communication would be provided. This would be desirable from many points of view. As other wayside wires would not exist, the special induction radio transmission line would be the most feasible and inexpensive means of communication to provide, since elevation would be neither required nor desired. The ideal location would be in the middle of the highway to serve all traffic lanes with equal efficiency. Where the construction of the highway or crossroads would interfere with the run of the wire for a short distance, the wire could be elevated or recessed without seriously affecting communication facilities, since the lateral distance to be bridged would not be very great, probably a small fraction of the distance represented by 157,000 feet divided by the frequency in kilocycles.

5 Fixed Station

The fixed station, such as a central or secondary station, is intended for use in establishing communication between a fixed point and mobile

units or with other fixed stations. Transmitting equipment at the fixed station covers a greater distance than equipment of similar power rating at the mobile station, because at the fixed station it is possible to transfer more signal energy from the transmitting source to wayside wires.

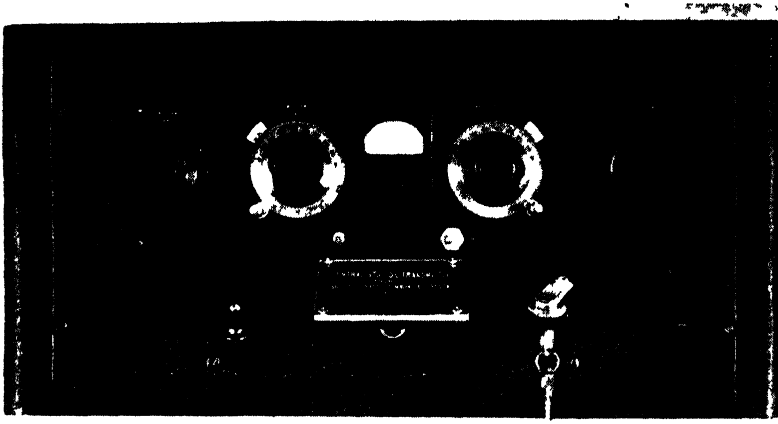
Signals from a microphone at the central station go into the transmitter, usually of 10 to 25 watts power rating. In the Halstead system,



Efficiency curves for loop vs. ground-laid cables. (1, 2, 3, are cables). (Courtesy Halstead Traffic Communications Corp.)

signal energy from the transmitter may go through a radio-frequency attenuator unit to facilitate regulation of the amount of power impressed on the wayside wires. A transfer relay is used in instances where the same RF induction cable is employed for transmitter and receiver.

The signals impressed on the wayside wires follow the conductors for the length of the signaling zone, usually 75 to 100 miles. Other fixed points



Central station transmitter with tuning door open (Courtesy Halstead Traffic Communications Corp.)

along the wayside pick up the signal inductively to provide communications at each point or to repeat, or boost, the signal along to the next zone. This process is repeated until the entire traffic lane is served from end to end, with alternate frequencies being used in adjoining zones to prevent mutual interference.

The induction field surrounding the wayside wires is employed in bridging the relatively small lateral gap between the wayside wires and a mobile unit proceeding on the railway tracks or highways running parallel to the wires. A loop or other suitable antenna on the mobile unit picks up the induction radio signal energy. By means of an associated receiver and loudspeaker on the mobile unit, the signals are reproduced within the vehicle.

With induction radio techniques as utilized in the Halstead system described above, it has been reported that wayside transmitting equipment having power output ratings of a few watts has provided usable voice signals in mobile units at distances of more than a hundred miles from the transmitting point.

6 Mobile Station

The mobile station in an induction radio system differs from the fixed station in that the transmitter on the vehicle usually employs greater power to obtain a communications range equivalent to that of the fixed station. This is necessary because the loop or other antenna of the mobile unit ordinarily is farther away from the wayside wires than is the coupling line at the fixed station. Also, the mobile loop must be of relatively small size, so as not to be too cumbersome or unsightly on a vehicle.

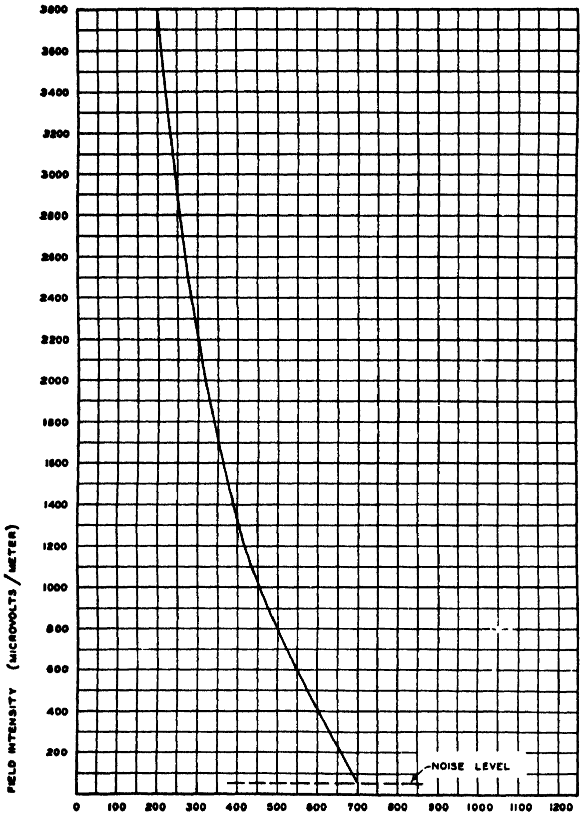
Greater interference from electrical equipment on or near mobile units is to be expected than at fixed stations, which normally are located at a selected point where noise levels are at a minimum. Loops must therefore be orientated to pick up maximum signal with minimum electrical noise. Otherwise, the mobile station operated efficiently and effectively at great distances from wayside points, often in excess of 100 miles. It is usually necessary, however, that the antenna on the vehicle be so disposed that effective coupling can take place between the loop of the mobile unit and the wayside wires, or vice versa. This is ordinarily the case in most areas, except in or near large urban areas where underground or shielded cables may be used.

The loops on mobile units, usually as employed in induction radio systems, may range in size from 12 by 30 feet for a very large mobile vehicle, such as a caboose or motor truck, to 1 by 1 foot in a smaller conveyance. In the larger loops, 4 to 6 turns of heavy copper wire, such as 10-gauge, are usually employed. The larger the cross section of the wire used in the loop, the lower the RF resistance, and the greater the efficiency. Usually, heavy multistrand wires are used. The smallest loops may utilize 15 to 25 turns of stranded wire. The loop is usually mounted in such a manner that the plane of the loop in normal operation is parallel to a vertical plane passing through the wayside wires. However, other loop orientations are employed on mobile vehicles, if more practicable. The aim in each case is to determine that the loop is located as ideally as feasible to effect maximum transfer of signal energy from the mobile transmitter to the wayside wires. The same loop is used in transmitting and in receiving in simplex systems.

To transmit from a mobile unit to a fixed station or other mobile units, signals from the microphone modulate the transmitter, the output voltage of which is impressed on the loop. The intense induction and radiation fields surrounding the loop induce a signal voltage on the wayside wires. Signals then follow the wires to the central station point where, as a result of the close proximity of the RF induction cable to the wire circuits or by means of a coupling capacitor, sufficient signal pickup is obtained. The signal then passes through the fixed station transfer relay to the receiver and thence to the loudspeaker. In simplex operation, two-way communications may be established between a control point and vehicles proceeding within a given zone extending for a distance of more than 100 miles. To exchange signals between mobile units, the signal is impressed on the wayside wires in the same manner.

In the Halstead induction radio system, a relatively low-power transmitter (25–50 watts) may be employed on the mobile unit. At strategically located wayside stations or zone control points, automatic repeater

equipment is used to pick up the signals induced in the line by the mobile unit. The signals then are retransmitted, or boosted, at high level for reception by other mobile units at any point along the traffic lane. Long-distance two-way communication thereby becomes possible for three legs



Attenuation curve with respect to overhead power and telephone lines. (Based on data of Halstead Traffic Communications Corp.)

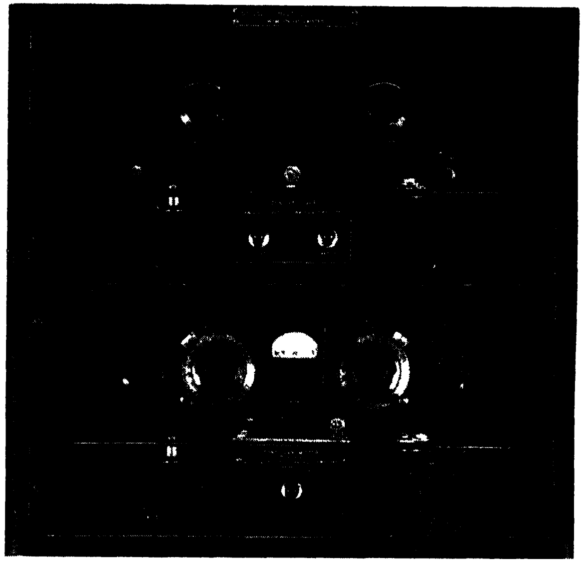
of communication: (1) fixed station to mobile station, (2) mobile station to fixed station, and (3) mobile station to mobile station.

7 Repeater or Booster Station

The signaling distances possible with simple nonrepeater systems may or may not be sufficient for all highway and railroad applications. The operating range is dependent on the power of the transmitter associated with the wire circuits; the operating frequency; the attenuation char-

acteristics of the wire circuits with respect to frequency; the sensitivity of the receiving equipment; the signal-to-noise ratio; the type of modulation (AM or FM); and other factors.

Where communications are to be extended over very long distances along a highway or a railroad, or where centralized control is desired, automatic repeater equipment, as in the Halstead system, should be used. The repeaters are located at strategic zone control points. A local microphone and loudspeaker are incorporated in the repeater equipment to

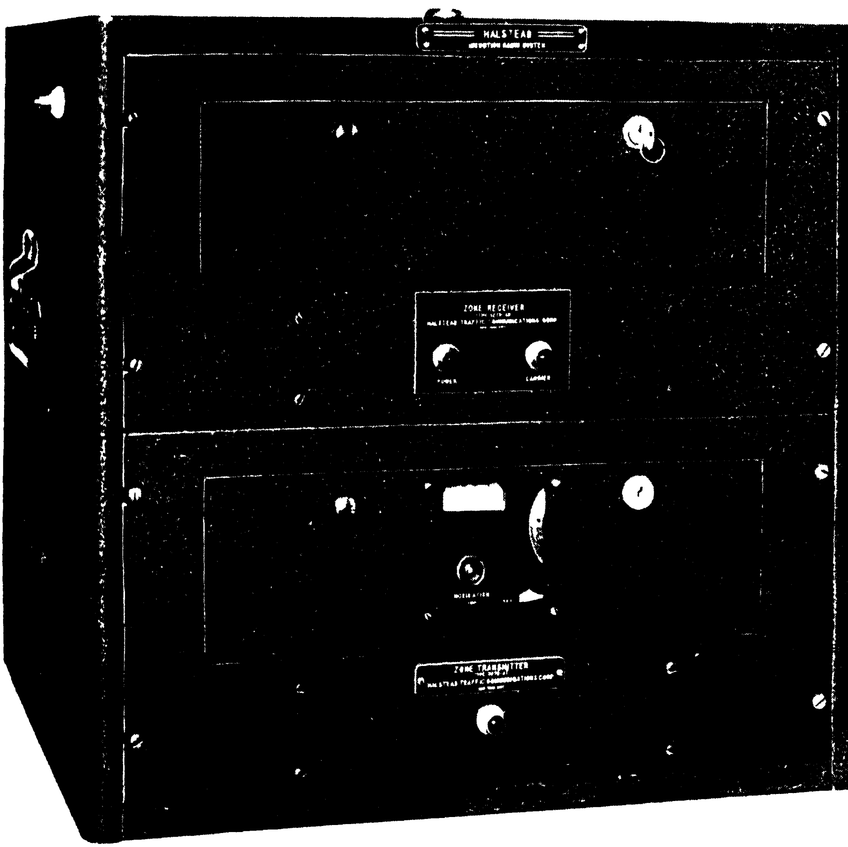


FM repeater station with tuning doors open. Ordinarily all controls are covered and doors are locked during operation to prevent unauthorized tampering. (Courtesy Halstead Traffic Communications Corp.)

facilitate its use for local zone communication as well as for normal repeater or booster functions. Signals from the central station or from mobile units are picked up by the receiving antenna, or by induction cable extending parallel to the wayside wires, or by capacity coupling to a low-voltage wayside wire circuit. Usually the receiving antenna is located within a few feet from these wires so that a relatively high signal-to-noise ratio may be obtained. Signal energy from the antenna is delivered to the zone receiver, and the received signal then is reproduced by the loudspeaker associated with this unit. A carrier-operated relay in the receiver is actuated by an incoming carrier signal, which in the case of repeater equipment turns on the associated repeater transmitter.

Signals from the zone receiver are then impressed on the input circuit

of the zone transmitter and are retransmitted on the different frequency assigned to the subsequent zone along the line. Signals from the zone transmitter pass through the RF attenuator unit into the induction cable and then are transferred onto wayside circuits. The repeated signals from the repeater transmitter are picked up on the mobile unit by means of



Automatic FM repeater station employed in the Halstead induction radiotelephone systems for railways and highways. (Courtesy Halstead Traffic Communications Corp.)

a two-channel receiver: in this instance, the carrier responsive to the frequency of the repeater transmitter and, in a preceding zone, responsive to the frequency of that transmitter. If more than two signaling zones with different frequencies are used or exist for any reason, the receiver on the mobile unit may have several push-button tuning switches or automatically controlled selection switches to effect operation of the mobile receiver on the frequency associated with the zone in which it is employed.

8 Checking Circuits to Indicate Operative Condition

Special checking equipment provides the operator of the mobile unit with positive and continuous indication that his equipment is in normal operating order to receive instructions from a central or secondary station or from other mobile units. This is of great importance in railroad operation where equipment failure, if not known in advance, can result in an accident. An automatic pulsing unit at the central station during quiet periods when no other communications are being handled, sends out a tone signal usually at intervals of 5 seconds. Each signal is of momentary duration. The pulsing unit incorporates a motor-driven or electronic time-interval switch which keys the transmitter at the desired time intervals for a fraction of a second. The tone signal employed to modulate the transmitter is usually of a frequency in the 300–1000 cycle range and is impressed on the input circuit of the transmitter during pulsing intervals, but is automatically removed during speech-transmitting periods.

To prevent interference between the automatic checking signals and incoming signals from mobile units or secondary stations, a carrier-operated relay in the central station receiver (called the pulse lockout relay) automatically suspends the pulsing operation as long as the incoming carrier signal is being received. The same relay operates a carrier pilot light employed as a visual calling signal or to indicate that a particular channel is busy.

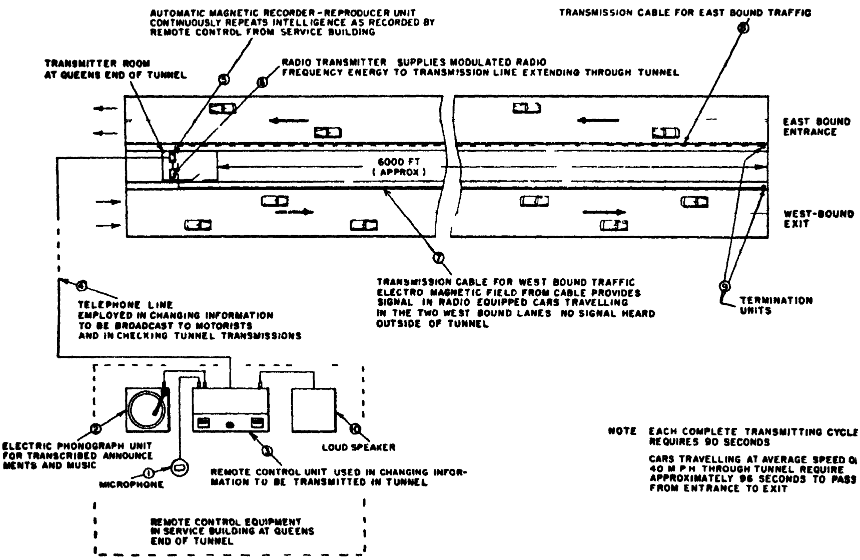
9 Automatic Highway Radio System for Motor Vehicles

A useful highway application of induction radio to serve private, commercial, or other motor vehicles has been developed by the Halstead Traffic Communications Corporation. During the World's Fair in 1940, it was successfully used as an experimental public service on the George Washington Bridge, which extends across the Hudson River between New Jersey and New York, to guide out-of-town motorists to the proper exits leading to various parts of New York City as well as to the major traffic arteries connecting with other cities. Modifications and improvements of this pioneer highway radio installation were used by the armed forces during World War II. It is expected that equipment of this type will be used in providing zone communications for automobiles, trucks, taxicabs, busses, and railroad rolling stock proceeding along traffic lanes served by the Halstead system.

Basically, this method comprises a small automatic radio transmitter tuned to a locally unoccupied frequency on the broadcast band or other portion of the radio spectrum. While frequencies as high as those in the broadcast band are less ideal for induction radio purposes than lower fre-

quencies, their use is justifiable because such an arrangement permits the motorist to receive the signals on the regular broadcast receiver in his automobile. The mobile station therefore requires no special equipment of any kind. The regular car antenna without modification or substitution may be used for radio reception.

In the original George Washington Bridge installation, a sign on the New Jersey side, reading "Highway Radio Ahead Tune 550 on Your Dial," informed the motorist of the existence of highway radio facilities on 550 kilocycles, at the low-frequency end of the broadcast band. This



Schematic diagram of Halstead Traffic Communications system, Queens Midtown tunnel experimental installation

frequency was employed because existing rules and regulations of the FCC permit a greater signaling field at the low-frequency end of the band than at the high-frequency end, which is approximately 1600 kilocycles. Also, tuning is broader at the lower frequencies, and therefore the driver can tune near rather than precisely at the top of the broadcast band in wave length.

Upon tuning his receiver to 550 kilocycles, the motorist immediately received useful and detailed routing information, without which a stranger driving into the city might become confused or lost or constitute a traffic hazard while stopping to read directional signs. The voice instructions were continuously and repeatedly transmitted by an automatic magnetic-tape recording and reproducing device.

When required, the message might be given directly by a police

officer or other authorized person, either at the wayside or from a central control point. By means of remote control facilities, if desired, information may be recorded from the central point and subsequently repeated by a wayside transmitter. This system can transmit traffic information, road and weather conditions, information about hotels, conventions, and civic activities, as well as entertainment, advertising, or good-will programs. State or municipal police can give information on speed limits and safe driving, thus carrying driver education directly to the man at the wheel at points of potential danger. Touring services conducted by commercial or municipal organizations to give supplemental road-map information, especially at congested or complex highway areas, can utilize this highway radio system to great advantage. It can also function so as to inform motorists who are on the wrong route and quickly guide them to the right road.

Although prerecorded information is sent automatically and repeatedly, the subject matter can be changed as often as desired, even at intervals of a few minutes. It is necessary merely for a central operator at a control point to press a button to erase electrically the magnetic recording by demagnetizing the recording tape. New recordings are then made by merely speaking into a microphone. The equipment at the wayside transmitting point is energized by regular electric lighting power; if that is not available, it can be handled by storage batteries which are replaced or recharged when necessary.

The equipment can be controlled locally at the wayside as well as by remote connection with a central point via telephone line. Once a recording has been made on the steel tape of the magnetic recording and reproducing unit, more than 100,000 repetitions may be transmitted without appreciable loss in signal level or quality.

It is also possible by means of automatic zone transmitters of this type to provide a program of entertainment and historical or scenic information as the tourist travels along the highway.

It is technically possible and feasible with the Halstead system to employ line facilities of the Bell Telephone Company or other communication organizations to permit automatic paging of trucks, busses, and private cars, and to utilize two-way induction radiotelephone equipment thereafter in maintaining communications for a desired interval. For example, a vehicle on the highway could communicate with any point in the world served by telephone through interconnections with regular telephone circuits.

The driver of a car equipped with a simple and inexpensive 10-watt induction radio transmitter and associated receiver, conceivably using a part of the same receiver employed for broadcast reception, would listen

Equipment to guide motorists into New York City over the George Washington Bridge during the World Fair (Courtesy Halstead Traffic Communications Corp.)

in for a moment to see if a selected frequency channel is clear. The individual would then call the Highway radiotelephone operator just as various small fishing and pleasure craft have for many years been able to call the marine telephone operator. Contact would then be established immediately with the telephone exchange, and a call might be placed to any fixed or mobile point within the domestic, international, aeronautical, or oceanic limits of the Bell Telephone Company and its widespread affiliates. A resaonable charge—25 cents a minute would be typical—should cover use of the induction radio facilities plus the normal domestic wire-connecting charge.

A similar service has been in effect for about ten years in marine radiotelephone applications. There the various radio manufacturers

supply and maintain the equipment, while a specific operating company, such as the American Telephone and Telegraph Company, provides the toll and connecting services.

Similar arrangements for all vehicles on highways and railroads are desirable and inevitable. It then would be unnecessary for transportation companies or individuals to install special fixed station facilities, which could not be so efficient or so continuously and capably staffed as a central station ready to accept or deliver a call at any time or place. Since the central station in each area would probably be staffed by professional maintenance and operating personnel, reasonably good signals from a mobile station operated by a layman would be satisfactory for use in repeater circuits of the telephone system, as the central station would transmit on relatively high power and with excellent signal quality, thus giving the mobile receiver a strong clear signal. The mobile station need not have elaborate transmitting equipment, since the central station can utilize extremely sensitive and efficient receiving equipment with optimum coupling to wayside wires, so that good two-way communication would be provided even if weak signals were received from the mobile unit.

Highway radio techniques will probably be more satisfactory than the marine applications, since good transmitting locations and close coupling to wayside wires exist in comparison with varying conditions of space propagation, which may depend on the earth conductivity and variable factors.

10 Carrier Communication over Power Lines

Another interesting application of carrier communication over existing wires is the equipment employed by major primary power-line networks which extend for thousands of miles throughout the world. The power transmission lines provide the path for guided radio signals instead of space transmission. This permits communication and control as well as co-ordination of activities between the generating source and the limits of the power-line network.

The following description of such carrier communication over power lines is based on Type KCA-325F6 equipment manufactured by the Link Radio Corporation for the General Electric Company. This equipment was developed to provide full automatic telephone service between stations of an electrical power network. It is designed to operate on a single-frequency basis to conserve the use of several frequencies and to provide means of establishing communication between three or more stations on a so-called party-line basis.

These sets are equipped with automatic dial calling and are arranged for operation over either four-wire or any standard two-wire telephone

extension for lines up to approximately 10 miles in length (1500 ohms loop resistance). A characteristic of single-frequency duplex operation is that the receiver is automatically cut out as soon as the user starts to talk and the transmitter comes on in its place. The transition time is extremely short and is barely noticeable in its effect. Because of this transfer (the transmitter and receiver both utilizing the same frequency) it is impossible to talk and receive at the same time, and as a result conversations over these sets differ from the ordinary telephone conversation. It is a characteristic that one becomes accustomed to very quickly, but it should be explained to the personnel who ordinarily will use it.

By the use of crystal-controlled frequencies, all stations on a given channel remain in alignment, which greatly simplifies the work of maintenance and assures a high degree of reliability. The equipment is completely self-enclosed in two standard steel cabinets, one of which houses the transmitting units and the other the receiving units. The only external connections required are the telephone line, power supply, and the concentric transmission line to the tuning units.

The single-frequency duplex method is similar in its operation to a single-frequency simplex, wherein the transmitter and receiver of all stations are tuned to the same frequency, and a push-button method is used to transfer from sending to receiving. In the duplex method, this transfer is done automatically by means of electronic control tubes, so that as soon as the operator starts to talk the receiver is blocked and the transmitter starts. When the operator stops talking, the set reverts to its original receiving condition.

Because there is no way for the set to distinguish between the operator talking and any extraneous room noises (or, in the case of long two-wire extensions, electrical disturbances), the following arrangement is used for protection: When an incoming signal is being received, a portion of the receiver output is diverted and rectified and the resulting DC voltage applied to the control tubes in such a way as to block the transmitter from operating. There are, however, certain limitations as to how far this blocking action may be carried.

In designing this equipment, the component parts were divided into thriteen different chassis and so arranged that each chassis would perform a definite function. This adds greatly to the flexibility of the equipment and allows the addition of special features, such as telephone extensions, or the elimination of any unnecessary features, as the particular installation may require.

The following list of chassis also indicates their functions:

1. The transmitter chassis contains the crystal oscillator, buffer, and RF amplifier tubes.

2. The modulator chassis contains all the components necessary to modulate the transmitter from an external source.

3. The control chassis contains the electronic tube circuits involved in effecting transfer from receiving to transmitting.

4. The four-wire chassis contains the equipment for four-wire extension telephones and the tone and timing circuits used for outgoing dialing.

5. The transmitter power supply provides all the voltages used in the transmitter.

6. The modulator power supply provides the voltages used in the modulator chassis.

The above units are all mounted in one transmitter cabinet. They are interconnected to the receiver cabinet which contains the following chassis:

1. The receiver amplifier consists of a three-channel amplifier to provide individual control for the handset volume, the input to the blocking amplifier, and the input to the dial selector.

2. The receiver chassis contains the RF, detector, and amplifier stages required for reception of carrier-frequency signals.

3. The selector chassis contains the stepping selector and associated relays to respond to the incoming dial pulses.

4. The revertive ringing chassis contains the ringing relays which ring the desired extension, and the revertive tone oscillator circuits, as well as the busy signal for the two-wire extensions.

5. The two-wire extension chassis contains the relays and amplifier necessary to co-ordinate the equipment when using a two-wire line or PBX connection.

6. The auxiliary power supply supplies plate voltage for the various control tubes and receiver.

7. The relay power supply supplies 48 volts for relay operation and microphone current for the telephones.

The following table lists the more pertinent characteristics of the KCA-325F6:

Nominal transmitter output: 25 watts.
Transmitter output impedance: 70 ohms.[1]
Modulation capability: 100 per cent.[2]
Sensitivity of receiver: 1.0 mv.
Selectivity of receiver: 6 kilocycles (band width).
Starting time: 10 milliseconds.
Restoring time: .25 seconds.
Effective AVC operating range: 90 db.
Power consumption (standby): 250 watts.
Power consumption (transmitting): 270 watts:
Selective calling: 2 digits; automatic, with revertive ringing.[3]

[1] This is intended to connect directly to the concentric cable. The set can be adjusted to work into any impedance between 30 and 500 ohms.

[2] The modulator has delayed AVC control which is normally adjusted to limit this to about 80 per cent over a wide range of voice levels.

[3] Revertive ringing refers to the system used whereby a tone is transmitted back upon completion of a call, to advise the person calling that the dialing was completed and that the called phone has rung.

CHAPTER TEN

FREQUENCY MODULATION

1 Discussion

A new era in two-way radio communication began in 1940 when the Federal Communications Commission recognized frequency modulation, making it possible for the first time in the United States to obtain assignment of operating channels and equipment licenses to employ FM in radiotelephony. Previously, only amplitude modulation was permitted in radiotelephony.

Communications began to utilize deviation ratios of 5 to 1. This was done by allocating channels 40 kilocycles wide for stations handling only voice frequencies, and 200 kilocycles wide for stations broadcasting music. To spare channels of such widths, the allocations were made in what is now called the very-high-frequency (VHF) band between 30 and 50 megacycles. This subsequently expanded into still higher frequencies.

Prior to the adoption of FM, all stations conveyed sound intelligence by varying the amplitude or power of the radio-frequency carrier waves generated by the transmitter. In this method, the amplitude-modulated carrier, while in transit from transmitting to receiving points, has characteristics that coincide too closely with static, noise, and electrical interference.

The terms "amplitude modulation" and "frequency modulation" are largely self-explanatory. In AM, the level of modulation (amount or volume of voice or other sound) is made to vary the amplitude of the radio-frequency carrier, but does not change the frequency or wave length of the carrier. In FM, the level of modulation varies the frequency or wave length, but does not change the amplitude or power of the radio-frequency carrier waves. Because FM is independent of amplitude variations, it does not coincide with the usual manifestations of static, noise, and electrical interference, either natural or man-made. As a result, FM enjoys higher signal-to-noise ratios. This makes possible more ideal communication both in intelligibility and in range.

In amplitude modulation transmissions, the variations of voice or

music produces side-band frequencies. For example, on the standard broadcast band, these side-bands were not allowed to exceed 5000 cycles upward or downward in frequency (total 10 kilocycles). This limitation was necessary to permit the maximum number of stations to operate in the United States at one time. Even then, the entire broadcast band between 550 and 1600 kilocycles could not accommodate more than about 800 broadcasting stations without serious interference. While a 10-kilocycle channel may be adequate for speech and some types of music, it covers only about one-third of the audible frequency range of the human ear. With FM, utilizing roomier spectrums, such as frequencies exceeding 30,000 kilocycles where suitable band widths and satisfactory deviation ratios are possible, the entire audible range of the human ear can be covered. This is done with maximum fidelity; what enters the microphone at the transmitter comes out of the loudspeaker at the receiving point with the most faithful reproduction.

FM has many advantages that AM does not have, particularly in the field of two-way communication. The single disadvantage—a problem only in the lower radio-frequency spectrum—is the greater amount of channel space required for each station. Within reasonable limits, the greater the frequency spectrum that each transmitting channel has, the more advantageous, so long as it does not exceed the natural band-pass of the associated receiver. Some well-informed persons claim that wide-band FM is preferable for better signal-to-noise ratios, but that narrow band is preferable for range. There are many pros and cons on that question.

Frequency modulation, that is, where speech or other modulation changes the frequency or wave length, is not new. In simple forms, it has existed since the earliest utilization of radiotelephony. Prior to 1940, it was prohibited because it created interference to other stations operating on or close to its frequency range. It was legalized only because it was to be used on such high-frequency bands as very high, ultra high, or super high, where sufficient frequency spectrum exists in any local zone to enable each station to have sufficient channel space and frequency isolation. As a result, the variations in frequency no longer have to operate on such narrow bands as to spill over and interfere with other stations.

During the many years that FM was outlawed, the usable radio-frequency spectrum totaled only about 1500 kilocycles, later increasing to about 30,000 kilocycles when short waves became available. By the time FM was legalized, the short-wave band had been extended still further, so that it was usable up to about 120,000 kilocycles. With microwave developments, it is being extended up to 10,000,000 kilocycles and even beyond.

As equipment and techniques constantly develop for functioning on

shorter and shorter wave lengths, the frequency spectrum increases in the same proportion that the wave length is reduced. These shorter wave lengths result in frequencies that have little or no reflection from the ionosphere. This, while making extremely long erratic ranges largely impossible, results in great advantages both for AM and FM. It makes the entire frequency spectrum available for reassignment every two to three visual horizons of distance that elevations comparable to the height of transmitting and receiving antennas above the earth would have. Such frequencies because of their direct and local range capabilities do not pick up the static and atmospheric noise which low-frequency sky-wave and erratic range signals ordinarily do. Some persons attribute the absence of static and interference to FM alone. In fairness to AM techniques and equipment, it should be pointed out that on frequencies being used by FM, which involve no reflected signals from the ionospheric layers, AM is also immune to static to a great degree. There, it is largely man-made rather than natural static which FM can minimize while AM cannot, at least to anything like the same degree.

In studying the subject of FM in radio literature, the reader is cautioned to check the publication date of the original printing of the book or periodical. In general, literature prior to 1940 usually discredits FM, while literature subsequent to that year, by the same authors, discusses it in favorable terms.

The single undertaking that gave FM a good start in two-way radio communication was initiated by the Connecticut State Police. This was the first system of its kind in the world and the first all two-way very-high-frequency system covering an entire state with no blank spots. It was an instantaneous success and since that time AM equipment for two-way communication has become increasingly obsolete for any but the more limited applications or where the frequency spectrum is inadequate, such as at the lower frequencies. It also smashed the optical horizon range theory by proving that the range was not dependent on the visual horizon, but was instead associated with signal-to-noise ratios and with the conductivity of the earth between the two stations. Instead of ranges of 1 to 10 miles from car to car, ranges in rural areas of 50 to 100 miles became more and more frequent, even in areas having partially obstructed horizons.

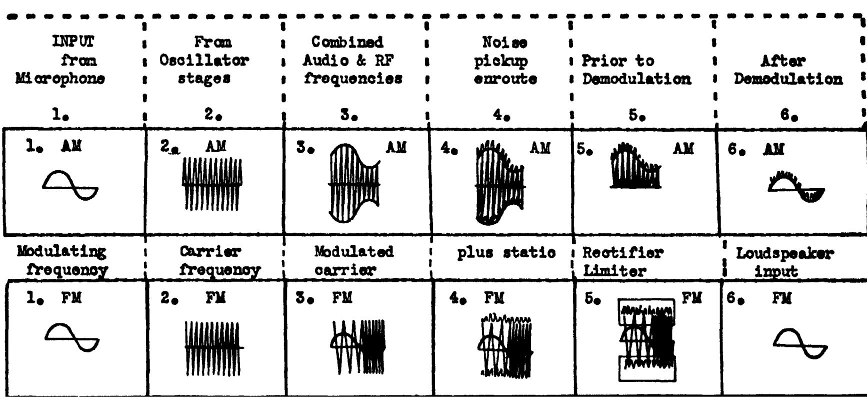
Prior to 1940, it was generally believed that two-way radio on ultra high frequencies (then 30 to 40 megacycles) was feasible and dependable for only a 1-mile radius, and in no case over 5 miles. That was on AM. However, the Cape Cod radio system, established on AM in 1937, disproved that theory, as it covered not less than 25 miles. Three years later, that radius was nearly doubled elsewhere by the use of FM equipment.

The trend toward greater range capabilities continues with better receivers, better antennas, and transmission lines, as well as by utilizing ideal deviation ratios.

2 How FM Reduces Static and Noise

Prior to the development of frequency modulation and very high frequencies, it was considered rash or ridiculous to claim that static could be eliminated. The initial development of FM was largely the result of efforts to overcome static as well as other disturbing interference to ideal reception.

The idea behind FM, when it comes to elimination of static or any objectionable interference, is to make the modulation of the radio carrier



Amplitude Modulation vs Frequency Modulation (for the same audio and carrier frequencies).

wave sufficiently different in its makeup and behavior, so that it coincides to a much lesser degree with undersired noises.

An elementary explanation of static elimination in amplitude modulation versus frequency modulation is shown in the accompanying chart in six steps as follows:

1. *Input from Microphone.* This is identical for both AM and FM. The voice applied to the microphone is converted into an electrical wave of a corresponding audio frequency. Consider this modulating frequency to be a traveler desiring to journey from the announcer's mouth at the transmitting station to the listener's eardrum at the receiving station. The frequency will not exceed 3000 cycles per second for speech.

2. *Carrier Signal from Oscillator Stage.* This is also identical for both AM and FM. Here is a much higher frequency carrier. Instead of 3000 cycles per second, this frequency depends on the wave length employed. It may be over 30,000 000 on the very-high-frequency band and may reach 10,000,000,000 cycles per second on the microwave band. Consider this high-frequency carrier to be the vehicle in

which the traveler will make his journey through space. The traveler, in effect, walked from his home (the announcer's vocal chords to the microphone) at sound speed of 1090 feet per second. He now is getting ready to board a fast vehicle.

3. *Modulated Carrier.* Here the traveler has boarded the vehicle preparatory to being carried from the antenna into space. AM and FM are now entirely opposite in their action.

The modulating frequency produced when speech was applied to the microphone has been impressed on the carrier frequency generated in the oscillator stage of the transmitter.

For AM, note that the amplitude height or power of the combined audio and RF frequencies has an envelope or outline which corresponds to the modulating frequency alternation, the amplitude of the envelope has increased; while for the negative side of the modulating frequency alternation, the amplitude of the envelope has decreased. It actually varies from zero to 4 times the unmodulated carrier amplitude. *The amplitude varies in accordance with the variations of the modulating frequency, but the frequency of the carrier remains unchanged.*

For FM, note that the amplitude of the carrier has not changed in value, but that the *frequency changed in exact accordance with the variations of the speech applied into the microphone.* This carrier frequency became lower for that half corresponding to the upper half of the modulating frequency sine wave; and became higher than shown in Step 2 for that half corresponding to the lower half of the modulating frequency sine wave.

4. *Noise Pickup En Route.* In AM, the traveler concealed in the envelope outline of the carrier frequency is now traveling through space, using the carrier as his fast means of conveyance at 186,000 miles per second. Static, lightning, and various atmospheric or man-made noises are picked up en route. These manifest themselves as increases in amplitude and *not* as changes in the frequency.

In FM, the same phenomenon takes place. The frequency has not changed but the static and noise pickup have changed the amplitude of the carrier. The traveler is buried in the frequency variations and not in the amplitude.

5. *Prior to Demodulation.* In AM, before the traveler can alight from the vehicle at the destination, the combined signal must be acted upon by the detector tube. There is both a positive and a negative alternation. If both went through, they would cancel out. One must be eliminated, so what remains will be unidirectional or pulsating DC. The modulation cannot rid itself of the static and noise because it exists as variations of amplitude. If the amplitude variations are destroyed, the modulation will also be destroyed. The frequency is still unchanged but now exists only for one alternation of each cycle.

In FM, that portion of the carrier which has irregular amplitude or superfluous amplitude is clipped off by a limiter tube. This tube is so energized that it cannot accept anything exceeding a certain amplitude for which it is designed. This level is kept low enough so that the static and noise cannot manifest themselves as increases of that amount of amplitude level. The frequency is still unchanged. The signal impressed into the microphone is still present and buried in the frequency variations. The noise cannot proceed any farther.

6. *After Demodulation.* The traveler has now arrived at the door of his destination. This corresponds to the loudspeaker winding. He has left the vehicle and when he opens the door, in effect, corresponding to being converted from an audio-frequency electrical wave into a sound-pressure wave when the loudspeaker winding varies the movement of the loudspeaker cone, sound-pressure variations

are produced in the room where the receiver is located. These sounds again travel at 1090 feet per second to strike the listener's eardrum and convey intelligence. It probably took longer to jump the small distances from announcer's mouth to microphone and from loudspeaker cone to listener's eardrum than it took to travel 50 miles through space. The former occurred at 1090 feet per second while the latter occurred at 186,000 miles per second. The listener hears the original sounds made by the announcer and also the static and noise picked up en route as variations in amplitude. He cannot separate this undesired noise by changing the volume control, since that will change the signal also. The signal-to-noise ratio will remain at the same comparative level whether loud or weak. He must have a stronger signal than noise, or communication becomes impossible in the case of AM.

In the case of FM, everything is the same except that the limiter in Step 5 clipped the noise off by permitting less signal to come through. The amount of amplitude clipped off could be tolerated, since the announcer's voice is buried in the frequency variations and will not be lost. It is now necessary only to amplify it to a level sufficient to make up for what was clipped off in the limiter. Since the signal is well above the noise level, it can stand considerable amplification and still provide a noise-free signal to the listener for all practicable purposes. The tube which permits converting the carrier-frequency variations into an audio frequency corresponding to that developed in Step 1 is called the discriminator.

3 General Advantages of FM

In addition to its ability to reject all forms of natural or man-made static to a much greater degree than AM, FM has the following advantages for two-day radio communication:

1. FM ordinarily possible two-way communication for distances at least 50 per cent farther than can amplitude modulation equipment for the same power output.
2. Since FM requires very little in the way of an audio system, it dispenses with not quite half of what the transmitter components would comprise for an AM system of identical output power in watts. The difference is not quite so much in the very lowest-powered equipment, but it approaches that point as the power of the transmitter increases.
3. For a given power drain from a storage or dry battery, FM equipment delivers about twice the output power than AM because of the elimination of most of the audio equipment necessary to modulate the carrier amplitude. This is of utmost importance in the case of a mobile station, such as an automobile having only a 6-volt battery. This same battery has many other functions in addition to operating radio equipment. A typical example is 22 amperes to operate 10-watt AM equipment or about 30 amperes for 15 watts AM, as compared to 25 to 27 amperes to operate 25 watts FM or about 45 to 50 amperes to operate 50 to 60 watts FM.
4. FM furnishes a signal as loud as desired without distortion to a greater degree than is possible with AM for the same substantial distance because of the better signal-to-noise ratio.
5. FM not only reduces static or atmospheric disturbances picked up in space during transit from transmitter to receiver, but it also minimizes or ignores

much other noise at the receiving location, whether externally or internally affecting the receiver. This makes for a much improved signal-to-noise ratio.

6. FM is ideal for utilization in the roomier and uncrowded frequency spectrums such as the ultra-high-frequency and super-high-frequency bands. There the receiver is inherently broad in kilocycles, and it is high desirable that most or all of this band-pass be utilized. If this band-pass, for example, is 200 kilocycles wide, it is preferable to use a frequency swing which will utilize that width rather than to employ AM with only 10 kilocycles occupancy and the remainder wasted.

7. FM completely ignores any other signal or interference if it has twice the signal strength or more strength than any other signal or signals.

8. FM reproduces speech, music, or tones with better fidelity and intelligibility over a much wider frequency range of sound.

9. FM does not produce a howl or heterodyning effect when two or more signals are on the air at the same time on the same or closely adjacent frequencies.

10. Each FM watt of output power is much more effective than an AM watt. It is a watt of fairly uniform amplitude. In the case of AM, it is an erratic watt fluctuating from zero to 4 times the unmodulated value of the carrier. The equipment does not have to be sufficiently oversized to handle this 400 per cent peak increase that maximum modulation involves with AM. There are times and situations, such as during lightning, when an AM watt may be useless while the FM watt can still provide useful communication.

11. For the same wattage output, there will be less maintenance and operating cost for FM.

12. For little or no difference in cost, FM equipment can be procured that has twice the amount of output power due to the more efficient FM watts, compared with equipment using the less efficient AM watts.

13. FM permits mobile units at some distance from each other to conduct local communications on the same channel without disrupting simultaneous communications by other mobile units also operating locally at a removed point.

4 FM Receiver

To receive frequency-modulated or FM signals, the receiver must have design characteristics that will enable it to respond to changes in frequency and not to changes in amplitude.

Very broad AM receivers, such as the superregenerative type, can also receive FM signals on very high frequencies with considerable effectiveness. For example, on 39,900 kilocycles, early systems used superregenerative receivers that have an inherent band-pass of about 360 kilocycles. No difficulty was experienced in picking up Mount Washington FM on a near-by frequency in most of the state of Maine for distances up to 200 miles. This could be done without more than a few random feet of wire for an aerial located inside the building. However, such a receiver did not have the advantage of the limiter action.

The modern FM receiver closely compares with the modern AM superheterodyne receiver. It differs principally as follows:

1. The IF amplifier has a higher gain and a wider band-pass. It must be wide enough to pass through the mean frequency plus the frequency deviations. For a

5-to-1 deviation ratio, this must be 30 to 40 kilocycles for a voice-modulated transmitter.

2. The last one or two IF stages are operated as limiter stages. The limiter removes any amplitude modulation resulting from noise, static, or electrical interference.

3. Instead of a detector tube converting amplitude variations into audio-frequency variations, a tube called the discriminator is employed to convert frequency variations into audio-frequency variations.

4. A better-than-average audio system is employed to make up for the signal reduction resulting from the limiter action. The improved signal-to-noise ratio existing in the FM receiver after leaving the discriminator makes it possible to utilize this increased audio amplification.

5. The loudspeaker should be better than average in order to take advantage of the higher fidelity and greater frequency of response that FM reception makes possible.

Otherwise, both the AM and FM receivers are virtually identical. It is necessary therefore to understand the functioning and the basic aims behind the limiter and the discriminator tubes in the circuit.

Limiter. The limiter stage or stages may be summarized as follows:

1. The last intermediate-frequency stage is called a limiter stage.

2. When more than one such stage is employed, the first one is called the first limiter, the next the second limiter, and so on. Typical modern equipment on 30 to 40 megacycles used by police and comparable services have three IF stages, two of which are limiters: the first stage is called IF; the second, first limiter; the third, second limiter. This means that the second and third stages are so energized and connected that they will reach saturation when a signal reaches a certain value. Anything having a greater amplitude will be unable to amplify to a value greater than a signal of lower input magnitude.

3. Prior to going through a limiter stage, the signal may vary both in frequency and in amplitude, the amplitude variations being in large measure caused by static or other interference picked up through the atmosphere or at the receiver.

4. When the signal leaves the limiter stages, all amplitude variations have been filtered out. The signal then varies only in frequency but at a reduced and uniform amplitude. This is even more completely the case when two limiter stages have been employed rather than one.

5. These limiter stages along with other IF stages are peaked for a suitable band width able to accommodate the deviation ratios used.

The limiter idea is not new. Radiotelegraph operators in the days of spark and arc transmitters operated in very heavy static or multistation interference and found it a valuable aid. As far back as twenty-five years ago, shipboard or coast stations used 90 volts B battery on the plate of the first audio tube, while only 22½ or 45 volts on the second audio tube. This permitted the feeble ship signal hundreds of miles away to build up to a value in the headphones comparable with the local stronger ship signal or heavy static. Both were limited to the 22½ or 45 volts plate

voltage on the last audio tube, which caused a lower saturation level. The saturation point is where an increase in the input signal no longer causes any additional amplification of the output.

The discriminator stage follows immediately after the last limiter stage. It is the counterpart of the detector stage or demodulator in the AM receiver. Its function is to convert the frequency variations back into audible variations. From that point on, there is no difference between AM and FM, as both methods handle the audio frequency as variations in amplitude to the loudspeaker. The only difference is that the FM signals after demodulation are more ideal but weaker than the AM signals and have to be built up with more audio amplification. Even then, an FM receiver still does not need more than two audio stages, which is what an AM receiver also needs for loudspeaker operation. It simply means that the FM receiver needs more of the amplification that is possible with two stages of audio than an AM receiver needs. A somewhat superior audio amplifier is incorporated in the FM receiver to take care of this extra amplification in quality equipment.

Interference by Undesired Signals. In FM, no appreciable difference is observed in the reception of a desired signal, until the undesired signal or signals, or even other interference, becomes at least half as great as the desired signal. This is in contrast to AM interference where considerable annoyance may be encountered even when the undesired signal is as low as 1 per cent of the desired signal.

In FM, when desired and undesired signals are on the threshold where they are equal or nearly equal, both may be heard, or one or the other as their relative strengths vary. They will not produce a squeal or heterodyne effect as do AM signals. This feature makes FM exceptionally useful in extensive relaying systems such as are necessary for long-range microwave communication setups. Then if a mobile unit picks up the same transmission from more than one point, no harm is done, as it responds to the loudest one. If both are equal or nearly equal, then the unit hears both points on the same announcement, and they blend together. When the undesired signal or signals have signal strengths greater than the desired signal, with the same mean frequency and deviation ratio characteristics, then, of course, communication is hopeless. But that would be true with any form of communication.

Band Width versus Tuning. The tuned circuits in the receiver must be capable of handling the frequency variations involved. This becomes increasingly simple as the frequency is increased. The receiver becomes inherently broader in band-pass as higher frequency spectrums are used. In the 30 to 40 megacycle band, the total frequency space necessary for a 5-to-1 deviation ratio, including a 25 per cent guard band as a pre-

caution against spillover into adjacent bands, is 40 kilocycles. At 40 megacycles, this is only one-tenth of one per cent of the radio spectrum. It becomes more of a problem on very low frequencies, such as used in induction radio communication for railroad and highway applications in conjunction with wayside wires. There, a low deviation ratio is necessary, as communication is confined to voice rather than music, so the modulating frequencies do not exceed 3000 cycles. However, deviation ratios of 3 to 1 have been used on frequencies as low as 100 kilocycles, and useful performance has been achieved even when the frequency deviations exceeded 5 per cent of the carrier frequency. On ultra high frequencies or super high frequencies, the receiver has more band-pass than is required for ideal FM deviation ratios, so this is not a problem at any time.

FM Receiver Tube Lineups. The block diagram of the FM receiver which was installed in the radio system of the police, fire, and public works department of South Portland, Maine, on 39,180 kilocycles, is shown here. In 1940, with this equipment, car-to-car communication up to 58 miles was obtained, in every case much more than horizon range. Since that time, equipment on the market has been further improved; typical tube lineups of more modern equipment of three manufacturers are given below:

	Link (A)		Motorola (B)		General Electric (C)
6AC7	RF amplifier	6SD7GT	RF amplifier	7H7	RF amplifier
6K8	First detector	6SD7GT	First mixer	7H7	First converter
6V6	Crystal osc. multiplier	6SD7GT	High-frequency osc. multiplier	7C7	High-frequency IF amplifier
6SH7	IF amplifier	6SD7GT	IF amplifier	7C7	Second converter
6K8	Second det. crystal osc.	6K8	Low-frequency osc. and second mixer	7C7	Oscillator
6SJ7	First limiter	6SD7GT	Low-freq. amp.	7C7	Low-frequency IF amplifier
6AC7	Second limiter	6SD7GT	First limiter	7C7	First limiter
6H6	Discriminator	6SD7GT	Second limiter	7C7	Second limiter
6H6	AVC, squelch filter	6H6	Discriminator	7A6	Discriminator
6SL7GT	First audio, squelch	6C8G	Squelch, first audio	7C7	Squelch amp.
6K6GT	Audio output	6SD7GT	Noise amplifier	7C6	First audio amp.
		6H6	Squelch	6V6GT	Power output
		6K6G	Power amplifier		

The following typical data on a modern FM receiver is based on the General Electric FM mobile receiver for the 30 to 40 megacycle band.

Sensitivity: 20-decibel noise quieting will occur at a signal input of not more than 0.4 microvolt.

Selectivity: 30 kilocycles at 6 decibels 120 kilocycles at 60 decibels.

Adjustable squelch: With no carrier on, the receiver will remain muted on all random noise. The squelch circuit automatically opens the receiver on a signal input as low as 0.1 microvolt, if desired—adjustable up to 0.4 microvolt.

Stability: Frequency variation within plus and minus 3.5 kilocycles.

Power output: 1.0 watt with 10 per cent maximum distortion.

Power supply unit: DC synchronous vibrator.

Power consumption: 5 amperes at 6 volts DC.

Circuit design: The receiver uses two cascade limiters and a double-conversion superheterodyne circuit. A single low-temperature-coefficient crystal controls both heterodyning frequencies.

5 FM Transmitter

The transmitter must have design characteristics so that audio electrical frequencies from the microphone circuit will result in changes of the frequency and not the amplitude of the radio-frequency carrier signal generated by the oscillator. To accomplish this, the transmitter is designed not only to generate a radio-frequency carrier, but also to shift the phase of a current derived from a source of fixed phase and frequency. It does this by an amount proportional to the amplitude of the modulating current and inversely proportional to its frequency. The variations of speech converted through the microphone are symmetrical with respect to the mean carrier frequency. These variations pass through this mean frequency in both directions (that is, upward and downward in frequency). This carrier frequency always returns exactly to the mean or stable frequency when the modulation ceases.

The carrier frequency shifts during modulation with respect to a fixed point known as the mean frequency. The Federal Communications Commission in the United States, or an equivalent regulatory agency in other nations, allocates the mean frequency as well as the amount that this frequency may shift with modulation.

The radio-frequency portion of either AM or FM transmitters is approximately identical except where crystal-control provisions are used. When crystal control is employed, more frequency multiplication is required. This is necessary because the modern crystal, such as the low-drift quartz type, resonates at a certain fundamental frequency dependent on its thickness. It is difficult to make this fundamental frequency shift more than a fraction of a kilocycle and still retain the characteristic of faithful return to the exact fundamental frequency for which the crystal is cut.

To employ crystal control with FM, the quartz crystal is cut for a sufficiently low frequency to give it sufficient thickness. It then is neither fragile or overcritical. A series of frequency-multiplying tube circuits is used to step it up to the desired output frequency. On the 30 to 40 megacycle band, employing a 5-to-1 deviation ratio, the frequency must swing

15 kilocycles maximum both above and below the mean frequency. Several leading manufacturers have standardized the use of two frequency quadruplers and one frequency doubler. This raises the frequency 4 by 4 by 2, or a total of 32 times that of the fundamental crystal frequency. As a result, the crystal need only fluctuate $^{15}/_{32}$ of a kilocycle higher or lower than its fundamental frequency to control the desired frequency deviation. The modern crystal functions satisfactorily under such conditions. Comparable AM equipment, where the modulation does not have to vary the frequency, employs less frequency multiplication by using thinner crystals cut for a higher frequency. There the frequency is usually multiplied 4 times. Some equipment raises the frequency 6 times.

While the FM transmitter requires more frequency multiplier tubes, these tubes are of the inexpensive and readily procurable receiving type having low power drain. The over-all efficiency of FM is sufficiently great to make this requirement unimportant; the simpler audio system more than makes up for it.

Audio System. The audio systems of AM and FM transmitters are radically different. FM has a very great advantage. For AM, an audio system must be provided that comprises components having size, weight, number, cost, and power consumption approximately equal to the entire radio-frequency carrier producing portion of the transmitter. Specifically, it must amplify the feeble microphone modulating current by a series of steps. In the case of the larger-powered transmitters, this may comprise in sequence: pre-amplifiers, speech amplifiers, modulator drivers, and modulators. Each of these steps up the power and requires up to several times the power drain of the preceding step. Each step requires increasingly larger and costlier tubes. This stepping up continues until the modulating equipment can develop an output in watts equal to 50 per cent of the maximum input power of the final (or largest) radio-frequency tube stage in the transmitter. Only then can the final radio-frequency carrier have its amplitude properly modulated in accordance with the applied voice to the microphone.

On the other hand, the FM system as used in two-way radio communication may employ no more than a pair of inexpensive receiving-type tubes used as phase modulators. These are placed between the microphone and the tube immediately following the RF oscillator. These balanced phase modulator tubes convert the microphone energy into differences of frequency for a low-power initial stage of the RF portion of the transmitter. It takes place before the frequency multiplier stages.

An FM system requires very little in the way of an audio system because modulation takes place in an initial low-powered stage of the transmitter. In AM it takes place in the final or highest-powered stage.

The difference becomes very great as the transmitter power becomes large. The difference is nearly twice the amount of equipment components, power consumption, and cost.

The FM equipment described in this book is principally based on the Armstrong method. This is essentially a phase modulation system in which the phase modulation is converted into frequency modulation. This is accomplished by making the phase modulation act inversely proportional to the modulating frequency.

Another method of producing FM is called the reactance method. This may employ a tube having a variable amplification factor such as is possible when the grid turns in a vacuum tube do not have uniform spacing. This variable mu tube is connected across the oscillator-tuned circuit in such a way as to look like a reactance to the tuned circuit. The magnitude of this reactance depends on the amplification of this tube, which in turn is controlled by the audio voltage impressed on the control grid.

The Armstrong method, while somewhat more complicated than the reactance method, has been more popular, since the various operations can be performed at low power with inexpensive receiving-type tubes. The reactance method because of greater simplicity is somewhat popular for low-power portable and amateur equipment.

Other methods such as those used in microwaves are also available. The Klystron or velocity-modulated tubes employing positive grids and negative plates can develop high deviation ratio FM by modulating the negative plate.

In addition, the Fonda-Freedman method, utilizing tubes of conventional structure on frequencies with periods shorter than the transit time of electrons from cathode to plate, also develops FM. This involves modulating the voltage of the plate or screen of selected types of conventional tubes, which controls the transit time of electrons, so that the current reaches the plate out of phase with the voltage. This results in a reactive component which will act as if the tank circuit has an increased capacitance if the transit time is made smaller, or as a decreased inductance if the transit time becomes larger. This changes the frequency of resonance and results in a new frequency which makes the reactive current equal to zero. This results in frequency modulation.

The question may arise as to whether FM is also advantageous for radiotelegraphy. The answer is that there is no difference betwen AM and FM except possibly for tone-modulated telegraphy. A radiotelegraph signal is of constant frequency and transmits intelligence by dots and dashes. These dots and dashes are nothing more than keeping the radio-frequency carrier signal on the air for shorter or longer intervals. A radio-

telegraph system has no audio system and utilizes no modulation. There is therefore no such thing as an AM or FM radiotelegraph transmitter. The transmitter is one and the same as far as radiotelegraphy is concerned.

FM Transmitter Tube Lineups. The accompanying block diagram shows the transmitter tube lineup of the system installed at South Portland, Maine, on 39,100 kilocycles. Listed below are the tube complements as used by three different manufacturers:

Link (A)		Motorola (B)		General Electric (C)	
2-7A8	Balanced modulators	2-7A8	Balanced modulators	7B7	Modulator
				7B7	Oscillator
7C7	Crystal oscillator	7C7	Crystal oscillator	7B7	First quadrupler
7C7	First quadrupler	7C7	First quadrupler	7B7	Second quadrupler
7C7	Second quadrupler	7C7	Second quadrupler	6V6	Doubler driver
7C5	Doubler driver	6V6	Doubler driver	807	Power amplifier
807	Power amplifier	807	Power amplifier		

The following typical data is based on the General Electric FM mobile transmitter used in the 30 to 40 megacycle band.

Power output: 30 watts.

Stability: 1.0 per cent of assigned frequency.

Modulation capability: Up to plus and minus 15-kilocycles deviation between 500 and 3000 cycles, corresponding to 100 per cent modulation.

Power supply unit: 6-volt dynamotor.

Power consumption: Standby operation, 2.1 amperes at 6 volts; full operation, 26.5 amperes at 6 volts DC.

Circuit design: The transmitter is of the direct, crystal-controlled phase-modulation type, with a total frequency multiplication of 32 times, using a specially developed single-tube modulator.

6 Deviation Ratio

In amplitude modulation, the frequency of the carrier signal is constant while the amplitude is varied in accordance with the modulating signal.

In frequency modulation, the amplitude of the carrier signal remains constant while the frequency is varied in accordance with the level of the modulated signal.

The varying of frequency with modulation is called the frequency deviation.

The amount the frequency deviates with respect to the modulating frequency is called the frequency swing.

The ratio of frequency swing to modulating frequency is called the deviation ratio.

The deviation ratio for an FM signal where both the frequency swing and the modulating frequency are expressed in the same units, such as kilocycles, is called the modulation index.

Figures for the South Portland, Maine, FM system are given here to show the use of the above terminology. The mean or resting frequency of the carrier without modulation is 39,180,000 cycles per second (39,180 kilocycles). For voice communication involving a modulating frequency not exceeding 3000 cycles per second, the FCC authorizes the system to vary in frequency for an amount not to exceed 15,000 cycles per second. In practice, this means the frequency varies between 39,165,000 and 39,195,000 cycles per second. It always returns to 39,180,000 cycles per second when no speech or sound is fed into the microphone while the button is depressed. This means that for each cycle of modulating frequency, the carrier frequency is displaced 5 cycles. This is a ratio of 5 to 1, which can be called either a deviation ratio of 5 to 1, or a modulation index of 5.

Just what the ideal deviation ratio should be depends on the circumstances and the application. There are conflicting opinions, and many radio authorities, including Major Edwin H. Armstrong, have been consulted concerning this discussion. The ideal deviation ratio appears to depend on the following:

1. Kind of sound to be transmitted, whether music or speech.
2. Width of IF band-pass.
3. Whether operations are conducted on higher or lower frequency spectrum.
4. Whether noise to be overcome is high or low in level.
5. Whether maximum range or maximum fidelity is required.

How much frequency displacement takes place with FM is dependent only on the amplitude of the modulating signal and is independent of the modulating frequency. This means that it is dependent on how loudly a person speaks into the microphone. The variations in the modulating frequency determine how fast the carrier frequency is displaced. It is not responsible for the amount of displacement. This means that if a higher frequency sound is fed into the microphone it displaces the same number of cycles in a shorter period of time than a lower frequency sound. It does not in either case change the carrier frequency except for differences in volume. For example, a bass voice has about one-third the frequency of a soprano. For the same volume of sound, each produces the same amount of frequency displacement, but the soprano requires the frequency displacement to take place three times faster.

It is estimated that a signal-to-noise advantage equal to the square root of 3, or 1.73, over AM exists for FM even with a deviation ratio of 1 to 1, as regards random tube and circuit noise. For pulse noises such as spark plug or ignition interference, it is about 2 to 1 instead of 1.73. This holds true only when the signal-to-noise ratio exceeds the critical threshold value. It becomes less, and in the opinion of some persons may even offer

no advantage over AM if it is less than this threshold value. For simplicity, let us consider the threshold to be the horizon. Although a few radio authorities still feel that AM can be more advantageous than FM for the same power and frequency, the majority of modern radio opinion is that FM is superior to AM in all situations.

Actually the noise encountered in radio can be of a nature which possesses variations both in amplitude and in frequency. The limiter takes care of the amplitude variations of such interference. To take care of the frequency variations of the same interference, a frequency swing or deviation ratio sufficiently different from the interference frequency variations must be employed. By making the swing sufficiently great, a larger signal-to-noise ratio is obtained in the output.

Equal deviation of frequency takes place on each side of the mean or resting frequency for each cycle of the modulating signal. Interference would have to do the same thing to be objectionable.

As the deviation ratio increases, noise suppression becomes better if, and only if, the signal is stronger than the noise. Where noise and signal become nearly equal, wider band FM would introduce more noise and limit communication. Low deviation ratios then make possible communication for additional range where AM would be impossible, and even high deviation FM would also be unsatisfactory.

The maximum or most ideal deviation ratio is different for each value of signal-to-noise ratio at the receiver. If that point is exceeded, the noise smothers the signal, and no advantage is realized. So long as that point is not reached, any increase in deviation ratio corresponds to better noise suppression.

Very successful performances have been achieved with ratios of 5 to 1 in police radio service on 30 to 40 megacycles. It would be even more successful if a higher deviation ratio were employed, provided the receiver circuits are capable of handling the increased frequency swing this would involve. The 5-to-1 ratio was selected not because it is the optimum ratio to ideal FM performance, but because of the necessity to conserve frequency spectrum in the bands where operations are desired. This computes as follows:

Voice (Police Radio, etc.) Not over 3,000 Cycles	Cycles	Music (Broadcasting) Not over 15,000 Cycles	Cycles
Above mean frequency........	15,000	Above mean frequency.......	75,000
Guard against spillover........	5,000	Guard (high side)...........	25,000
Below mean frequency........	15,000	Below mean frequency	75,000
Guard against spillover........	5,000	Guard (low side)............	25,000
Total 40 kilocycles or.......	40,000	Total 200 kilocycles or... .	200,000

If this were doubled, the signal to noise would improve 4 times. If it

were increased 10 times, it would improve as the square of 10, or a total of 100 times. It improves as the square of the increase in deviation, provided the signal is above the threshold. Below the threshold, the higher the deviation ratio, the more unsatisfactory it becomes. It then is desirable to use decreased deviation ratio.

A high deviation ratio should be used when a high signal-to-noise ratio and utmost fidelity is desired. A low deviation ratio should be used for voice where less fidelity and maximum ranges are desired for beyond-horizon distances.

As the wave length employed becomes shorter, the frequency spectrum becomes correspondingly larger. The receiver becomes correspondingly greater in frequency response, so that IF circuits can handle greater deviation ratios. It then becomes more and more advantageous to use wider and wider band modulation, so long as it does not approach the limits of the receiver inherent band-pass. Just how far this may go can be surmised from the table below. The following conditions might prevail where a 25 per cent guard band against spillover is included in each case. Modulating frequency based on voice or 3000 cycles per second maximum (3 kilocycles).

Condition	High-freq. Band-pass 10 Kc.	VHF Band-pass 100 Kc.	UHF Band-pass 1000 Kc.	SHF Band-pass 10,000 Kc.	Gain over AM Within Threshold
AM occupancy	80%	8%	.8%	.08%	–
FM 1-to-1 "	80%	8%	.8%	.08%	1.7
FM 5-to-1 "	impossible	40%	4%	.4%	1.7×5^2
FM 10-to-1 "	"	80%	8%	.8%	1.7×10^2
FM 25-to-1 "	"	impossible	20%	2.0%	1.7×25^2
FM 100-to-1 "	"	"	80%	8%	1.7×100^2
FM 500-to-1 "	"	"	impossible	40%	1.7×500^2
Ideal FM ratio receiver and threshold permitting, for 100 per cent occupancy	1.25	12.5	125	1250	$1.7 \times$ ratio^2 for random noise $2.0 \times$ ratio^2 for pulse noise

Advantages of wide-band FM (that is, high deviation ratios) are said to be:

1. Higher signal-to-noise ratio.
2. Better dynamic range.
3. Less interference.
4. Higher fidelity.
5. Greater flexibility should same channel be used for more than a single application, for example, speech and facsimile.

Major Armstrong's testimony before the Federal Communications Commission in 1940 on FM stated that tests showed an improvement in

range of approximately $2\frac{1}{2}$ times of a narrow band over AM on the same frequencies, and a further increase of nearly two in favor of wide-band FM.

An opposing source, having great commitments in AM facilities and techniques, has gone on record as stating that, other things being equal, the wider band systems require more transmitter power to produce a signal which will be above the threshold. For that reason, they argue, optimum deviation ratio is unity (1 to 1) or the same amount of frequency utilization as AM for maximum readibility and transmission distance. The author's experiences have been more in line with Major Armstrong's testimony.

In any case, this book is concerned with two-way communication principally on voice, utilizing lower modulating frequencies. Much of the challenge so far has been with regard to broadcasting, utilizing much higher modulating frequencies. More varied and more numerous tests will have to be made before this question is completely settled. In any case, 5 to 1 has given excellent results that AM could not duplicate in the field of two-way radio. It remains to be seen how much more ratio can be advantageously used.

Most prewar two-way radio development was undertaken in the frequency spectrum between 30 and 40 megacycles, and therefore overcrowded conditions in that part of the radio frequency spectrum has developed.

As a result, the Federal Communications Commission in 1945, in connection with its postwar frequency allocation plan, has proposed reducing the maximum modulating frequency from 3000 to 2500 cycles per second, and to reduce the deviation ratio from 5-to-1 to 3-to-1. This would reduce the channel width to 20 kilocycles instead of 40 kilocycles, thereby doubling the number of stations which can be accommodated using FM.

This new trend has caused much concern among the established services already equipped and operating in that frequency region. The over-all result will be to reduce intelligibility and to lessen the advantages of FM over AM for noise rejection. This reduction, while pronounced, is not expected to be serious for most of the existing two-way radio services.

The human voice has a fundamental frequency in the range of 100-to-300 cycles per second. The lower figure represents the masculine bass, and the higher figure the feminine soprano voice. In order to have sufficient intelligibility, we must have several harmonic frequencies or overtones in addition to the fundamental frequencies. This can be seen in terms of a newspaper photograph. The fundamental frequency might compare with a photograph made up of insufficient dots—enough to show the general picture but not enough to show details. The more dots

used, the sharper the detail—up to the point where it becomes solid black. Within the normal limits of the human ear, the more harmonics or overtones, the better the quality of the sound and the more intelligible it becomes. The minimum modulating frequency may vary with the sounds. Syllabic vowel sounds are intelligible at lower frequencies than syllabic consonant sounds. In practice, modulating frequencies lower than about 800 cycles per second are not sufficiently intelligible. Satisfactory intelligibility requires a modulating frequency exceeding 1500 cycles per second. It should be much more, preferably, 3000 cycles has heretofore been found satisfactory, although more would have been better. The proposed use of 2500 cycles satisfactory even though somewhat less clear.

In analyzing the modulating frequency of 2500 cycles per second, with respect to the proposed band of 20 kilocycles, the following is found to result. If 25 per cent spillover is allowed to protect adjacent channels, 15 kilocycles remain. Since the frequency swings both upward and downward, half of that figure, 7½ kilocycles, will be utilized. Since the modulating frequency is limited to 2½ kilocycles, the carrier can only swing 3 cycles for each cycle of modulating frequency. This is a deviation ratio of 3-to-1 or a modulation index of 3, as compared to the former 5.

The advantages of FM over AM in rejecting noise is therefore substantially decreased. Within the threshold region (where the signal exceeds noise), the advantage of FM over AM is equal to the square root of 3 times the modulation index squared. This compares as follows:

Deviation ratio 5-to-1 $= 1.73 \times 5^2 = 1.73 \times 25 = 43.25$ times
Deviation ratio 3-to-1 $= 1.73 \times 3^2 = 1.73 \times 9 = 15.57$ times

Thus the advantages of FM over AM are reduced to approximately one third of what it has been. This is still of substantial proportions and could continue to render effective service for most of the applications and areas involved in two-way radio communication. In a few very unfavorable radio communicating areas, this might be inadequate. But communication should still be possible.

The reduction of the deviation ratio in this case might permit narrower natural receiver band-pass design. There is less noise picked up and an increased operating range with a narrow band-pass. This would offset some of the disadvantages that a lower modulating frequency and narrower channel might have.

7 Signal-to-noise Ratio

In every radio application, there must be a signal that is above noise in order to have communication. Noise may comprise any one or more of the following:

1. Atmospheric or natural static such as thunderstorms, lightning, static electricity, or an oncoming storm. These may come not only over the direct

path of the signal between desired transmitting and receiving points but from any direction to which the receiving antenna is responsive. On frequencies too high for ionospheric reflections (usually above 30,000 kilocycles), much of this type of interference is not picked up. On microwave frequencies, where sharply beamed or focused antennas are used, giving gains up to several hundred times that of a nondirectional antenna, a corresponding immunity to static is to be expected.

2. Man-made static and electrical interference from neon signs, blinking traffic lights, commutator brushes, electric razors, sparking contacts, ignition systems, and the like.

3. Thermal agitation or random noise produced in the receiver vacuum tube circuits as they fluctuate in connection with their normal functioning.

In addition, signals may be arriving by more than one path and with different distances and arrival times. This causes them to come in with different magnitude, phase, and time. This may be additive if arriving in phase, or subtractive if of incorrect phase. The latter condition causes fading. The higher the antennas are elevated above the earth, the greater the time difference between the direct and the indirect paths, and the greater the likelihood of having maximum signal strength.

Maximum signal with respect to noise is provided by frequency selection, deviation ratio, transmitter power, receiver sensitivity, receiver amplification, receiver band-pass, correct transmitting-station and receiving-station antennas and transmission lines by clearing the curvature of the earth; and by varying the frequency instead of the amplitude with modulation.

The signal-to-noise ratio can be improved by increasing the transmitter power. This is not feasible or economical in mobile stations because of cost, power drain, size, maintenance, and operating considerations. It is preferable to do it by using FM with the ideal deviation ratio—one which provides maximum signal and readability improvement with minimum disturbance of a favorable signal-to-noise ratio. How far to go in this connection is limited by the increased noise picked up over the wider resultant range of frequency. It is not anticipated ordinarily that the extra noise picked up by using a wider band will overcome the other advantages accruing to the signal strength for distances less than the radio horizon.

8 AM versus FM

In AM, if the frequency varies with modulation, it is considered to be a distortion and is not desired. In FM, if the amplitude varies with modulation, it is likewise considered a distortion that must be clipped off by the limiter and not allowed to pass. FM can do that, whereas AM cannot. However, recently a technique has been developed which makes possible the elimination of amplitude variations or disturbances during FM reception, as well as eliminating FM disturbances during AM signal

reception. It utilizes a circuit arrangement where AM and FM cannot live together. This opens the way to eliminators rather than limiters, and makes them applicable to either AM or FM receivers.

If speech is too loud or overmodulated with AM, the amplitude rises to an excessive value which can overload the equipment. In FM, if speech is too loud, more frequency deviation is utilized, merely reaching into the guard or spillover band.

In the Armstrong system, modulation takes place in an early stage, usually the stage immediately after the oscillator, and it is done at low radio frequencies. The frequency is then stepped up by the use of the frequency multipliers, such as 32 times.

It is estimated that for random noise, such as tube noise, the following comparisons hold:

$$\frac{\text{FM signal-to-noise ratio}}{\text{AM signal-to-noise ratio}} = 1.7\ \frac{\text{Frequency deviation}}{\text{Modulating frequency}}$$
$$= 1.7 \text{ times the deviation ratio}$$

For ignition noises or other pulsed types, change 1.7 to 2.

COMPARISONS OF FM AND AM FOR VARIOUS SITUATIONS

Situation	*Frequency Modulation*	*Amplitude Modulation*
Transmitted signal that leaves the station.	Wave form remains unchanged regardless of amount of voice. Only the amount of frequency has changed.	Constantly varies in amplitude from zero to 4 times the unmodulated carrier value. A loud sound fed into microphone will go to maximum, while a weak sound barely manifests itself. Frequency remains unchanged.
What happens when the level of modulation is changed (when louder or softer sounds are uttered into microphone).	The louder the voice or higher the modulation level, the greater the frequency shift each side of the mean frequency.	Carrier level is greatest when loudest; lowest when sounds are softest.
How variations of pitch, tone, voice, or music are made possible, aside from variation in loudness at the microphone.	Controls the time required to produce the amount of frequency shift necessary for any modulation level.	Reflected in the side-bands with respect to time. This cannot exceed the authorized side-bands.
Amount of frequency required.	Depends on the deviation ratio or modulation index. For 5-to-1 ratio it is 40 kilocycles for voice and 200 kilocycles for broadcasting, of which 25 per cent is not actually utilized. This excess is to safeguard against spillover into an adjacent band.	This is known as side-bands. FCC limits this to less than 10 kilocycles over-all. (5 kilocycles each side).

FUNCTIONAL COMPARISONS FM VERSUS AM*

	AM	FM
Carrier frequency.	Remains constant.	Varies with modulation.
Amplitude of RF carrier.	Shape and amplitude vary with level of modulation.	Remains constant.
Radiated power.	Power varies with modulation.	Remains constant.
Frequency deviation.	Remains constant except for side-bands.	Depends on *level* of the modulating frequency, not dependent on the modulating frequency itself.
Effect of modulating frequency.	Varies width of side-bands.	Merely determines how fast the carrier frequency shifts.
Effect of two stations operating simultaneously on same frequency.	Produces intolerable and unintelligible howl. One station must be 30 to 100 times more powerful to break through the other.	Louder station predominates particularly if twice as strong. May fluctuate between one and the other, but usually both never heard together. Very small zone may occur where slight flutter or both may be heard together. No squeal or howl at any time.
Effect of static, lightning, ignition, or induction interference.	Susceptible to all these.	Evident only when it has a frequency and wave form that covers conditions of operation. Automobile ignition can be weakly heard if inadequately filtered when carrier is on.
Intelligibility.	Good for local ranges, when able to override all interference.	Good for full horizon and frequently several horizons.
Range.	Maximum about 20 per cent beyond horizon ordinarily.	With squelch on, about same as AM or slightly better. With squelch off, the hiss comes in on standby position, but signals can be heard twice as far as AM. This is for identical stations and areas.
Equipment cost (prewar).	$200 to $500 per car.	$275 to $425 per car.
Maintenance.	About same as FM.	About same as AM.
Battery consumption (6 volts).	Superregenerative receiver draws 3.6 amperes. Superheterodyne receiver draws 5 to 6 amperes. AM 10-watt transmitter draws 22 amperes.	FM receiver draws 5 to 6 amperes. FM transmitter draws 26 amperes but delivers 25 watts output. Available with 50 to 60 watts output, drawing up to 50 amperes.

* From "AM vs. FM in Two-Way Radio," *Radio News*, December, 1943.

FUNCTIONAL COMPARISONS FM VERSUS AM.*—(*Continued*)

	AM	FM
Number of tubes in car installation.	Superregenerative receiver has 4 tubes. Superheterodyne receiver about 9. Transmitter 4 or 5.	Receiver has 11 or 12 tubes. Transmitter 7 or 8 tubes. FM uses more tubes, but they are of inexpensive and easily procurable type with low consumption.
Coverage.	Inconsistent at horizon. Within horizon ranges quite consistent.	Consistent at all times and even well beyond the horizon. Better over-all coverage.
Frequency band required.	Can operate on 10-kilocycle band.	Present equipment needs 30-kilocycle band with 10 kilocycle extra for guard against spillover into adjacent band. If it had wider band would perform clearer and stronger.
Final detection.	Uses second detector.	Uses discriminator.
Last IF stages.	Uses second and third IF.	Uses first and second limiters. These are IF stages, but their amplitudes cannot exceed a selected value equal to the weaker amplitudes to have uniform amplitude to the discriminator.

LIMITATIONS OF AM AND FM IN ACTUAL PRACTICE*
Values taken on a range test in Maine, car to car

Areas	Distance Miles	Coverage
Quoddy to Calais	25	AM dropped out at 12 miles. FM covered the entire area and 18 miles beyond Calais with an inconsistent area at 12 to 18-mile zone due to terrain.
Eastport to Columbia Falls	58	AM worked 25 miles with bad and frequent blank spots after 10 miles. FM held signal for 49 miles and then worked intermittently 9 miles more.
Wiscasset to Portland	53	AM undetermined. FM worked spottily from Wiscasset to Bath, but thereafter was consistent for last 40 miles into Portland.

* From "AM vs. FM in Two-Way Radio," *Radio News*, December, 1943.

These original tests were made with 25 watt 25UMF against the IOMT transmitters equipment using bumper antenna. Since that time the Maine State Police have substantially exceeded these performances by using 50 or 60 watt FM transmitters with roof-top antennas.

CHAPTER ELEVEN

MICROWAVES

1 Discussion

To provide two-way communication for all those who can use it legitimately, there must be a frequency spectrum in which to operate that is free from the interference of other stations. The microwave band provides such a spectrum, as it is considered to comprise wave lengths between 1 centimeter and 1 meter in length. This corresponds to frequencies between 300,000 kilocycles and 30,000,000 kilocycles.

Microwaves are the radio wave lengths that most closely approach the spectrum and behavior of light, having the behavior of both very-high-frequency radio communication and of an invisible beam of light. It is easy to focus microwaves or relay them for substantial distances. Where physical obstructions stop their passage within the line of sight, they may be reflected or relayed onward. They cannot utilize ionospheric reflections and are useful only for direct path communication. As a result, the vast frequency spectrum of microwaves is available again for reuse every 50 to 100 miles on the earth's surface in every direction. Here at last exists room and opportunity for every necessary radio application. Here also can be provided the ideal deviation ratios to obtain the most ideal behavior from frequency modulation.

Professor Elihu Thompson, in his 1924 Kelvin Lecture at the Institution of Civil Engineers in London, stated that the theory of a "heaviside layer" (ionosphere) was unnecessary, since all radio waves are guided by the earth, which is the real conductor, just as is the wire in guided-wave telephony or telegraphy. He illustrated his theory by claiming that the ideal condition for radio would be a smooth copper earth in a vacuum. He indicated further that this theory seems to be well supported by the well-known fact that much greater distances are possible over water than over land, although this theory is believed to be unpopular with mathematicians.

The late Guglielmo Marconi, in a lecture before the Royal Institution of Great Britian on December 2, 1932, had the following to say about

microwaves, more than thirty-five years after his invention of wireless, or radio:

> The general belief is that with electromagnetic waves under one meter in length, usually referred to as quasi-optical, communication is possible only when the transmitter and receiver are within visual range of each other and that consequently their usefulness is defined by that condition. Long experience, however, has taught me not always to believe in the limitations indicated by purely theoretical considerations or even by calculations. These, as we well know, are often based on insufficient knowledge of all the relevant factors. I believe, in spite of adverse forecasts, in trying new lines of research, however unpromising they may seem at first sight. I decided again to take up the systematic investigation of the properties and characteristics of the very short waves in view of the palpable advantages which they seemed to offer, that is, the small dimensions of the radiators, receivers, and reflectors necessary for radiating and receiving a considerable amount of electrical energy, and in view also of the fact that they do not suffer interference from natural electrical disturbances. The permanent and practical use of microwaves will be, in my opinion, a new and economical means of reliable radio communication, free from electrical disturbances, eminently suitable for use between islands, and to and from islands and the mainland, and also between other places separated by moderate distances. The new system is unaffected by fog and offers a high degree of secrecy by virtue principally of its sharp directive qualities.

Mr. Marconi spent much of his later years and efforts with considerable success in the field of microwaves. That he was entirely correct is demonstrated by the success he achieved with microwaves, using wave lengths half a meter long or less. He achieved ranges up to 168 miles in the Mediterranean areas where his theoretical horizon was only supposed to be about 70 miles maximum. Even without the advantages of FM, modern tubes, and techniques he was able to communicate more than two horizons of distance. He demonstrated that microwaves afforded extraordinary and plentiful opportunities to permit all persons, who desired or needed to do so, to annihilate distance and isolation.

When Hertz first demonstrated the hertzian waves, about 1886, which led to Marconi's development of wireless, he did it on microwaves using wave lengths that did not exceed 60 centimeters. Wireless functioned without vacuum tubes for the first several years and was obligated to use long waves. It took new tubes developed during the past five years to make microwaves feasible. Microwaves and FM became important about the same time. Together they make an excellent combination for future radio development.

2 Frequency Spectrum

Prior to about 1925, wave lengths shorter than 200 meters were considered largely unsatisfactory, being unpopular even among radio amateurs. Communication was based on sky-wave ranges, and wave

lengths shorter than 200 meters were not dependable for that during several hours out of the twenty-four. By stopping at wave lengths of 200 meters, the useful radio spectrum was limited to 1500 kilocycles total.

When radio operations were conducted entirely above 200 meters, the spark and the arc, frequently with simple crystal receiving equipment, was the usual form of radio equipment. When amateurs were compelled to shift to wave lengths shorter than 200 meters, they began to employ vacuum tubes, as spark transmitters became unfeasible. They were amazed to discover that with very small power and most modest equipment, frequently costing less than $10 for odd parts, they were getting phenomenal ranges. A single UV201A tube with less than 5 watts power actually communicated as far as Australia, about 12,000 miles. A drastic revision of radio thinking took place. The spectrum was extended down to 10 meters, corresponding to a maximum of 30,000 kilocycles, or 20 more than had existed before. This still was not enough, because each channel was capable of interfering up to many thousands of miles, thereby limiting the number of users.

When police, fire, and forestry services decided they needed two-way radio, they penetrated further downward in wave length or upward in frequency. This opened up 7½ to 10 meters in wave length, corresponding to 30,000 to 40,000 kilocycles. Then FM and television needed room and penetrated further, that is, above 40,000 kilocycles. As the threshold was crossed between frequencies that had sky-wave reflective behavior and those that did not act in that manner, two advantages developed. One was that a short amount of wave length added to the spectrum represented an enormous amount of frequency. At the same time, these frequencies were

Band	Total Wave Length Spectrum in Meters	Total Frequency Spectrum in Kilocycles	Maximum Number of AM Channels (8 Kc.)	Maximum Number of FM Channels (40 Kc.)	Average Number of Kilocycles per Meter Wave Length	Average Number of Meters per Kilocycle Frequency
Very low frequency	20,000	20	2.5	nil	.001	1000
Low frequency	9,000	270	33.7	6.7	.03	33.3
Medium frequency	900	2,700	337.5	67.5	3	.333
High frequency	90	27,000	3,375	675	300	.00333
Very high frequency	9	270,000	33,750	6,750	30,000	.0000333
Ultra high frequency	.9	2,700,000	337,500	67,500	3,000,000	.000000333
Super high frequency	.09	27,000,000	3,375,000	675,000	300,000,000	.00000000333

useful only for horizontal distances and did not reflect back great distances from the ionosphere. Not only was there more frequency space, but frequency space became available over again about every 50 miles.

Now we are at the point where a meter (3.28 feet) is too long a dimension, and we use centimeters (.0328 foot) to describe the wave length. Also, the frequency now becomes so large a number in kilocycles that we have to use megacycles (million of cycles or thousands of kilocycles). To the microwave enthusiast, wave lengths longer than 1 meter or lower than 300,000 kilocycles are long waves or low frequencies. The microwave band has penetrated well below 5 centimeters or well above 6000 megacycles. Just how much further the penetration is beyond that point cannot be publicized during World War II.

Thanks to microwaves, the postwar frequency spectrum largely utilizable is over 100 times greater than the entire prewar frequency spectrum at its maximum level.

On the lower frequencies, the equipment and techniques have been known for a longer time, but the spectrum is insufficient to accommodate all the stations desiring to operate there. On microwaves, the spectrum is more than ample for the present generation, but the equipment and techniques are not too well known by the rank and file of the radio fraternity. However, that condition is changing rapidly, largely because of the many civilians and members of the armed forces who built and operated much equipment in this spectrum during World War II.

The minimum AM communication channel for modulating frequencies (voice) not exceeding 3000 cycles per second is 8 kilocycles, of which 25 per cent represents precautions against spillover into an adjacent channel.

The minimum FM communication channel for the same modulating frequencies, using a deviation ratio of 5 to 1, is 40 kilocycles. However, FM can be as low as 8 kilocycles by using unity deviation ratio or can be almost any amount greater than that, as determined by multiplying the deviation ratio by 8.

A spectrum analysis terminating in microwaves is shown on page 199.

The useful radio spectrum therefore extends from zero to 30,000 megacycles, corresponding from 1 centimeter to infinity in wave length. Beyond that frequency or below that wave length spectrum lies the following (roughly approximate):

	Megacycles	
Experimental radio	30,000 to	1,000,000
Infrared	1,000,000 to	100,000,000
Visible spectrum (light and colors)	100,000,000 to	500,000,000
Ultraviolet	500,000,000	50,000,000,000
X rays	50,000,000,000 to	5,000,000,000,000
Gamma rays	5,000,000,000,000 to	100,000,000,000,000

With need and with time, the radio engineers and physicists will penetrate further and further into frequencies higher than the microwave band. One centimeter is equivalent to 30,000 megacycles, but that is only a billionth part of a gamma-ray frequency. The surface has not even been scratched.

FUNCTIONAL COMPARISONS VHF VERSUS MICROWAVES*

Consideration	Very High Frequencies	Microwaves
Wave length band.	1 to 10 meters.	1 centimeter to 1 meter.
Frequency band.	30,000 to 300,000 kc.	300,000 to 30,000,000 kc.
Maximum number of possible channels for AM. (10kc)	27,000.	2,970,000.
Maximum number of possible channels for FM (40kc) using present 5-to-1 deviation ratio.	About 1350.	About 148,500
Suitability for FM.	Very desirable but more suitable for AM because less space available and more power can be utilized.	Ideal. Functions with little power and as horizon proposition. Plenty of frequency space to use higher deviation ratios without exceeding receiver band-pass.
Natural receiver band-pass.	Usually less than 100 kc.	Can be a megacycle or more at the high-frequency end of band.
Maximum deviation ratio feasible for maximum clarity and signal strength without exceeding receiver natural band-pass.	3 to 1 unless receiver has band-pass exceeding 100 kc.	About 300 to 1. Signal clarity and signal strength can be 100 times greater than for VHF.
Effect of sky waves.	Definitely interferes with distant points frequently at low-frequency end.	Thus far unknown to have been picked up on sky waves. It would be phenomenal and rare if ever.
Frequency stability.	Good and lends itself to crystal control at low-frequency end.	AFC which keeps receiver locked to transmitter frequency is dependable. Crystal control to stabilize transmitter still undeveloped.
Power output.	Any amount possible but little point to use over 25 watts.	Microwaves superior because able to use less than ¼ watt. Because of deviation ratios, receiver band-pass, signal-to-noise ratio, and

* From "VHF vs. Microwaves in Two-Way Communication," *Radio News*, May, 1944.

FUNCTIONAL COMPARISONS VHF VERSUS MICROWAVE*—(*Continued*)

Consideration	Very High Frequencies	Microwaves
		beamed transmission it can conceivably be as much as 10,000 times more efficient as that of AM for comparable power.
Antenna design.	Must be conventional.	Can be a variety of types including the conventional types if cut for microwave band. Also wave-guide and parabolic types.
Focusing and beaming.	Possible but usually not done because of physical dimensions of antenna array. A half-wave length may be as much as 16 feet long.	Very simple to attain. A half wave may be as small as a fraction of an inch or a maximum of 18 inches. Gains up to 2000 are possible.
IF stages.	Can be anything desired.	Usually at VHF.
Coaxial cable.	Can be used reasonable distances.	Only feasible for very short lengths due to high attenuation. Better techniques available because of frequency.
Circuit layout.	Conventional with leads kept short.	Must be properly designed so that inductance and capacitance will be minimized. New techniques are employed.
Fading.	Ground wave within horizon is stable. Beyond horizon it is unstable. FM may penetrate somewhat beyond horizon.	Stable within horizon line of sight.
Effect of secondary barriers such as trees, brush, small solid objects.	Usually unnoticed.	Susceptible to objects larger than wave length employed and width of beam used.
Cost.	This is now somewhat stabilized. Police radio equipment about $500.	Not yet stable. One group claims it will be about $200 per station complete.
Interference.	Considerable on AM. Minor on FM.	Should be less on microwaves.
X-ray and diathermy effects.	None.	Very slight diathermy effect immediately in front of antenna within few inches if very high power used. No X-ray effect.

* From "VHF vs. Microwaves in Two-Way Communication," *Radio News*, May, 1944.

FUNCTIONAL COMPARISONS VHF VERSUS MICROWAVE*—(*Continued*)

Consideration	Very High Frequencies	Microwaves
Effect of weather.	Works better and farther in wet weather, such as rain, snow, high humidity.	Same to lesser degree.
Interelectrode capacitance.	Of minor importance.	Of major importance.
Size.	Moderate or small.	Will be much smaller.
Circuit transit time between elements. Its effect on phase and polarity.	Minor.	Important.
Future trend.	Zenith is in sight. More expansion by radical reshifting of stations.	Unlimited opportunities at present.

* From "VHF vs. Microwaves in Two-Way Communication," *Radio News*, May, 1944.

3 Limitations of Microwaves

Microwaves are susceptible to primary barriers such as the curvature of the earth, which limits the horizon. They are also affected by physical obstructions forming the topography of the earth, as these obstruct the optical and radio path between transmitting and receiving points; these may be hills, mountains, forests, dense jungle, or tall structues, which are larger than the cone of radiation from the transmitter.

Microwaves can be handled both as a conventional radio signal and as a beam of light. Think of them as behaving like very high frequencies as on the 30–40 megacycle band plus the effect of a searchlight at night. Remember that microwaves are the radio frequencies closest to the wave length of light. While still very far removed from the light spectrum of frequencies, they actually have some of its qualities. These do not have to be of a very pronounced degree in order to be detected on very sensitive radio receiving equipment employing the high amplification possible in modern radio vacuum tubes.

Whereas, for ideal performance on the lowest radio frequencies, the ideal antenna would have to be too long to provide conveniently, on microwaves the antenna becomes extremely short. An antenna for any radio frequency has to be associated with at least a half-wave length in space, or a quarter-wave length when used in conjunction with a ground. On very low frequencies, for example, 15,000 meters (20 kilocycles), a half-wave length becomes several miles in dimension. On the standard broadcast band, it may be 300 to 900 feet long; on short waves, between 15 and 300 feet; on the ultra-short-wave band, anything up to 15 feet. However, on the microwave band, it can be as small as a fraction of an inch.

Because of this extremely short antenna dimension, techniques not possible on lower frequencies can be utilized. It is actually possible to take the antenna and locate it with respect to a reflecting dish or mirror to concentrate and focus the radiation. The antenna element propagating electromagnetic waves is not allowed to dissipate radiation in every direction, most of which is ordinarily wasted. Instead, it is made to act as the equivalent of a light source with the antenna element directing the radiation toward the reflector. This reflector is a parabolic dish of the right shape and dimension to receive the radiation and focus it into space in a highly concentrated beam. How wide this beam will be and just what shape it will have depends on the shape and dimension of the parabolic dish and the placement of the radiating element in front of it. To facilitate having all the radiated energy striking the dish before bounding off into space, a half-wave reflector is made part of the tiny antenna array and located in back of the radiating element proper. As a result, excellent control of all the radiated energy is attained within reasonable limits.

This concentration of radiated energy will of course be picked up in direction only as the reflector shape and angle may permit a beam of light to be picked up. It travels in a straight path. However, encountering an osbtruction does not necessarily mean that the signals will not be picked up beyond, as this depends on the shape, size, and contour of the obstruction encountered. To a very limited degree but often sufficient to provide additional radio communication, it depends also on how well the obstruction acts as a reflector itself—that is, as if it were a glass mirror, and the beamed transmission, a beam of light. What a beam of light would do when it strikes a mirror of that shape and contour is what the microwave radio transmission will do to a small but frequently useful degree.

A microwave communication system should be designed so that between all communication points there is an unobstructed line of sight. If that cannot be provided, then there are two principal lines of attack:

1. By providing automatic or manual simple booster or repeater stations which can, if desired, be also used as local communication points (as discussed in the microwave section of Chapter 12).
2. By providing special reflectors of the right shape and size to pick up the radiation and redirect it around or beyond the obstruction.

Some additional communication is usually possible due to the guided paths resulting from conducting paths present, such as railroad trackage, wayside wires, good conducting earth, moisture, or adjacent stream.

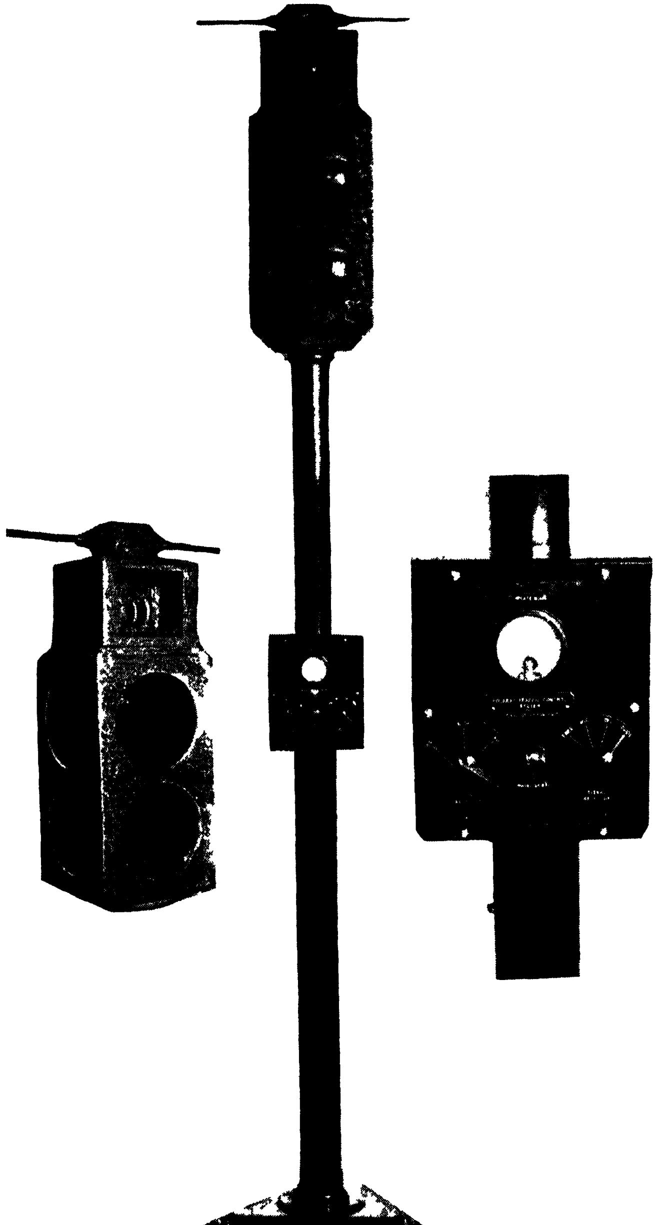
A new term "Trapping" is sometimes used to denote unusual conditions in the atmosphere which may enable microwaves to have ranges much greater than can be associated with any computation. It appears to be a narrow zone between sharp changes in atmospheric densities

which may guide signals at such heights above the earth as to make possible ranges very much greater than the transmitter's horizon.

4 Advantages of Microwaves

The advantages of microwaves as compared to other radio frequencies, that is, frequencies lower than 300,000 kilocycles, are:

1. Unlimited frequency channel space. Specifically, the spectrum is approximately 10 times the combined spectrums of very low, low, medium, high, and very high frequencies.
2. This spectrum, in addition to being so plentiful is available again for reutilization every 50 to 100 miles in every direction on the earth's surface without likelihood of interference. The dimensions of the earth are sufficiently great to provide at least 10,000 such areas of separation.
3. The signal can be beamed or focused in any desired beam width and beam shape. This concentrates the power, increases the signal and range, and occupies only a small sector of a single channel. The signal is not wasted above, below, to the right, or to the left of, the radiated beam. If desired, it may utilize no more than a few hundredths part of a sphere. As a result, gains in power equivalent to 100 to 1000 times are possible in the desired direction of communication, with a corresponding diminution in the undesired directions.
4. The wave length is sufficiently small so that a half-wave-length antenna is of such dimension and size that it can be employed with parabolic reflectors or directive arrays.
5. The wave length is naturally suitable for wide-band FM. Although the receiver responds only to a very small amount of wave-length difference, the amount nevertheless may represent hundreds and even thousands of kilocycles. The receiver band-pass is sufficient to provide any practicable desired deviation ratio. This makes possible an incomparable signal-to-noise ratio and excellent fidelity. As a result, there is increased range, as compared with AM under similar circumstances.
6. There is freedom from static and much natural or man-made interference to ideal reception. Atmospherics definitely do not manifest themselves.
7. Signals are consistent in signal strength and range with their minimum performance predictable within close limits for all times, areas, and conditions.
8. Signals can function very efficiently with very low transmitter power because of the high frequency of the propagated electromagnetic waves, aside from the gain resulting from the use of focused transmission.
9. Equipment can be very compact and light in weight, have low power drain, and be inexpensive so far as material and fabrication costs are involved.
10. Equipment can be utilized for extended and closely controlled areas of communication as it adapts itself for use in conjunction with communication-booster or repeater stations, which, if desired, may have all these functions within the same instrument.
11. The frequency spectrum is sufficiently great to permit any number of stations likely to need or desire radio facilities. It can also give each of these stations a completely free channel, if desired, and this channel can be much wider than heretofore used. This greatly simplifies the necessary frequency tolerance and control to guard against spillover or interference with an adjacent channel, which is otherwise technically complex as well as costly to provide.



Experimental microwave equipment used for radio traffic control systems. (Courtesy Halstead Traffic Communications Corp.)

12. Microwaves will supply additional range coverage and signal strength if any of the following conditions exist between the transmitting and receiving points:

(a) Rain, snow, ice, mud, swamp, marsh.
(b) Railroad track of endless length.
(c) Adjacent landlines.
(d) Conducting minerals in the earth that have suitable outcropping.
(e) Metallic structures that are well grounded.
(f) Lakes, rivers, brooks, and streams.
(g) Oceans, including bays, inlets, and coves.
(h) Canyons and contours that behave like wave guides; sometimes tunnels will also do this.
(i) Other conditions permitting reflections that are not recognizable.
(j) Temperature inversion producing conditions above the surface of the earth, usually during summer over bodies of water, which extend the horizon considerably farther.

5 Circuit Considerations on Microwaves

As compared with lower frequencies, microwave equipment cannot tolerate random or slipshod design techniques. The necessary techniques are not difficult but must be recognized. They involve the following principal considerations:

1. The reactance of circuit inductance in ohms increases with frequency. It becomes virtually an insulator to alternating current while still remaining an excellent conductor for direct current.
2. The reactance of circuit capacitance in ohms decreases with frequency. It becomes virtually a perfect conductor for alternating current while still remaining an excellent insulator or block to the passage of direct current.
3. Ordinary insulation behaves more like a resistance than an insulator. Instead of insulation, it is better to take advantage of the infinite or zero impedances existing every odd quarter-wave length.
4. The transit time in the circuit and within the tubes.
5. The frequency in cycles per second is so high that in the space of time it takes to travel from cathode to grid to plate it may arrive with a change in phase and consequently in polarity. This is called phase change or phase reversal.
6. The space between the elements in the tube, such as between grid and plate, cathode and plate, cathode and grid, forms important amounts of interelectrode capacitance. This makes necessary the use of nonconventional tubes except where conventional tubes are used with nonconventional techniques.

The effect of super high frequencies on capacitance and inductance may be appreciated better by the following analysis.

Resistance in Ohms. This is the opposition that a material offers to the flow of either DC or AC. It is minimum in a good conductor such as copper, and maximum in a resistor such as carbon. Glass or porcelain materials are resistors to such an extent that DC virtually does not pass; they are distinguished from ordinary resistors by being called insulators. These

insulators become decreasingly effective for AC as the frequency is increased.

Inductive Reactance in Ohms. This is the opposition which inductance, such as a coil of wire, offers to the flow of AC. The more inductance in a circuit and/or the higher the frequency, then the higher the inductive reactance. This has no effect on DC except where it changes the circuit resistance. The formula for inductive reactance is:

Inductive reactance in ohms   6.2832 × frequency in cycles per second × inductance in henries.

Capacitive Reactance in Ohms. This is the opposition which capacitance, such as a condenser, can offer to the flow of AC. The more capacitance and/or the higher the frequency, the lower the capacitive reactance will be. In any case, the DC in a circuit cannot pass through the capacitance, regardless of size and the AC frequency. The formula for capacitive reactance is:

Capacitive reactance in ohms

$$\frac{1}{6.2832 \times \text{freq. in cycles} \times \text{capacitance in farads}}$$

Total Reactance in Ohms. This is the total reactance existing from inductance and capacitance in series. It is computed by subtracting the capacitive reactance from the inductive reactance. Note that capacitance acts oppositely to inductance above.

EXAMPLES OF REACTANCE FOR VARIOUS RADIO FREQUENCIES
For 10 millihenries of inductance and .01 mfd. of capacitance

Frequency Band	Frequency Kilocycles	Inductive Reactance Ohms	Capacitive Reactance Ohms	Total Reactance Ohms
Very low	10	628	159,154	
Low	100	6,283	15,915	
Medium	1,000	62,832	1,591	61,241
High	10,000	628,320	159	628,161
Very high	100,000	6,283,200	15.9	6,283,184
Ultra high	1,000,000	62,832,000	1.59	62,831,999
Super high or microwaves	10,000,000	628,320,000	.15	628,320,000

From the above it can be seen that, as the frequency is increased, capacitive and inductance exchange functions so far as opposition to the flow of alternating current is concerned.

So trivial does capacitance reactance become on microwaves that a wave-guide line may be partially wrecked to be discontinuous and still permit normal operation. The separation in the wave guide becoming no more than a condenser, in effect, for which the reactance is almost zero. A capacitance can afford a better path for AC at microwaves than can

an inductance at the lowest radio frequency. This creates interesting conditions and possibilities, requiring completely revised radio thinking as compared with older radio techniques.

Impedance Expressed in Ohms. This is the total opposition to the flow of AC, resulting from the resistance and total reactance in a circuit. The formula for impedance is:

Impedance in ohms = square root of resistance squared plus reactance squared.

Q of a Circuit Expressed in Whole Numbers. This is the ratio between inductive reactance and the resistance of a circuit. As the high-frequency current surges back and forth in a radio resonating circuit, the energy shifts alternately back and forth between the magnetic field of the inductance and the electric field of the capacitance. Each time that occurs, some energy is lost. This loss occurs every cycle. Whereas, on induction radio frequencies, it might occur 100,000 times per second, on microwaves it may be anything between 300,000,000 and 30,000,000,000 times a second, depending on the exact frequency being employed. An analogy is to compare it with a swing. Once the swing begins to sway, it loses only a small amount of sway each time it goes back and forth. This can be easily compensated for with a small amount of push.

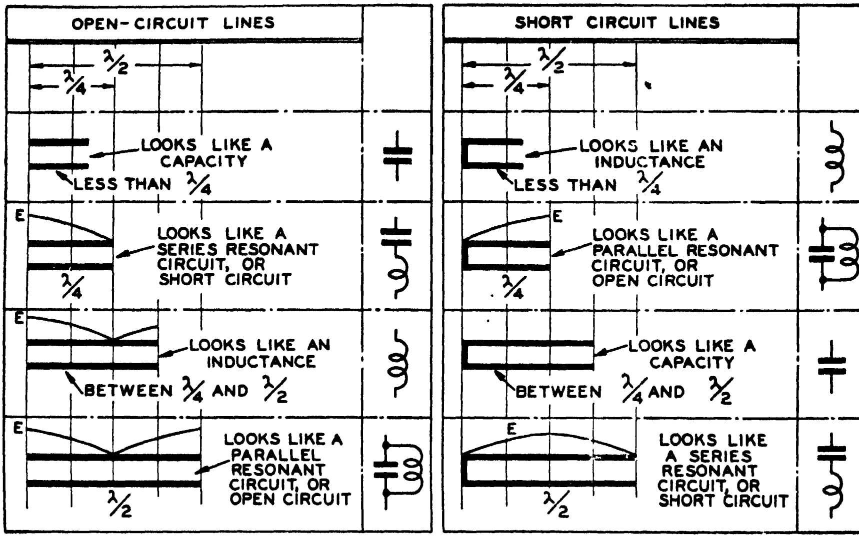
In radio circuits, this loss is compensated for by a constant small amount of power replenishment by the vacuum tube oscillator. This Q—figure of merit or quality—should be reasonably high. When it is high, it will not die off rapidly as does a spark type of oscillation, and it will tune sharply and selectively. On low frequencies, it is difficult to develop a sufficiently high Q because the inductive reactance in ohms is low. On microwave frequencies, a high Q is easy to attain because the inductive reactance is very high, so high in fact that it may have to be given consideration so that the circuit will not be too efficient for comfort.

Inductance-Capacitance Ratio in a Circuit. A circuit must have a definite total value computed by multiplying the values in henries and in farads of the inductance and the capacitance respectively. This includes everything in the circuit and the tube that goes to make up inductance and capacitance. Their product must be

$$\frac{1}{(6.2832 \times \text{frequency in cycles})^2} = \text{LC}$$

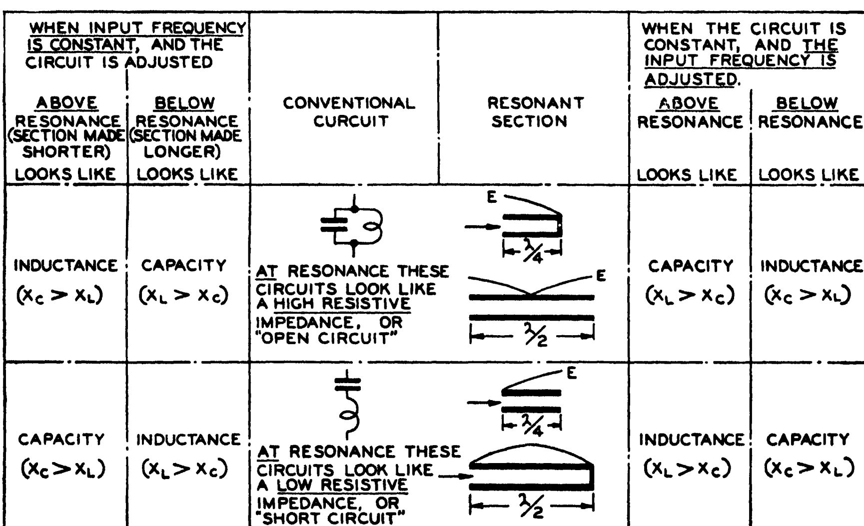
where L equals henries
C equals farads

Just what part of this shall make up inductance and what part shall comprise capacitance depends on the application. On the higher fre-



CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED.

Characteristics of line sections.



TUNED LINE CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED

Tuning characteristics of resonant sections and conventional circuits. (From "Practical Analysis of Ultra High Frequency," by J. R. Meagher and H. J. Markley. Courtesy of RCA Service Co., Inc.)

quencies, increasing the inductance tends to increase the reactance much faster than the resistance. On microwaves, there is already some inherent inductance and capacitance within the tube itself, which cannot be completely eliminated. This may be almost sufficient by itself, so that very little additional inductance or capacitance is required externally. Tuning on all frequencies is possible because inductance is opposite to capacitance in effect. In a series circuit, when the inductive reactance subtracted from the capacitive reactance equals zero, the circuit is in tune. When it is not zero, then the circuit is not in tune, and special provisions become necessary to produce circuit resonance.

In tuning IF stages, it may not be feasible to use a suitable small capacitance, as it changes the frequency too much with a small amount of adjustment. A popular method is to insert a metallic slug, either solid or made up of iron filings, inside or outside the coils. As the slug is moved toward the center from either direction, the frequency increases, with maximum frequency attained when the slug is in the middle of the coil. This results in passing the resonant point twice, as the slug goes through the coil—that is, each side of the middle.

Resonance attained exactly in the middle of the coil is undesirable, since it provides no leeway in tuning further. The number of turns on the coil should be changed; slightly more added for lowering the frequency, or some removed for increasing the frequency.

Capacitance and inductance can be changed also by spacing the turns. It is therefore important that the coils do not change their spacing with respect to their adjacent turns once the equipment is built, as that would change the frequency range of the equipment.

The ideal insulation does not exist. Materials successfully used with losses that can be tolerated are polystyrene, micarata, mica, and other forms of plastics or ceramics having infinitely high resistance.

On microwaves it may not be feasible, except possibly on the low-frequency end of the spectrum, to provide special frequency-control provisions in the transmitter. Instead, it is simpler to equip the receiver with a good automatic frequency-control circuit (AFC). This circuit "chases" the transmitter electronically back and forth, as it may fluctuate small amounts in frequency. On 3000 megacycles, tested equipment has been able to follow it as much as 15 megacycles, although such extremes were not necessary. In any case, it demonstrated its ability to follow transmitter as far as the latter was able to drift.

6 Tubes Suitable for Microwaves

Ordinary receiving and transmitting tubes operated in a conventional manner are unsatisfactory for operation on microwaves to generate or

detect the frequencies involved. They do not function properly for the following reasons:

Transit Time. On high frequencies, the transit time in the region between the cathode and the plate within the tube is comparable with the period of oscillation. For example in free space, an electromagnetic wave travels 186,000 miles per second. On low frequency—for example, 100,000 cycles per second (100 kilocycles)—one cycle involves a hundred-thousandth of a second. In that time, a wave travels nearly two miles, so the change of phase of that wave over a distance of an inch is trivial. On microwaves, however—for example, 10,000,000,000 cycles per second (10,000 megacycles)—one cycle involves a ten-billionth of a second of time. In free space, a wave travels only about an inch. Inside a vacuum tube, it travels slower than it does in free space so the condition is even worse, depending on the magnitude and polarity of the charge at any instant on the various elements. An alternating effect starting with one magnitude and polarity may reach the next element with something entirely different. This is called phase reversal.

Phase Shift. The phase shift decreases the active component of the current and consequently the power available at the plate, which connects with the output credit. It also results in a reactive component which changes the resonating characteristics of the tuned circuit connected with the tube.

Grid Conductance. On frequencies as high as required for microwaves, grid conductance takes place which increases the energy dissipation. This dissipation results in the heating of the plate in the tube. The grid conductance tends to deprive the plate of amounts of useful power, which can actually exceed the plate output. When this condition exists, the circuit cannot oscillate.

Interelectrode Capacitance. When the interelectrode capacitance is too high, it requires high charging currents. This increases the ohmic losses in the circuit. This, in turn, results in too little power output or even no useful output. When these ohmic losses are too high, the tube fails to oscillate or function.

To operate on microwave frequencies, four different tubes or techniques are used. Others are under development, but full disclosure is considered inadvisable at present. The four techniques are:

1. Conventional tubes, designed or very-high-frequency or ultra-high-frequency operation.
2. Klystron type of tube, employing velocity modulation technique.
3. Magnetron.
4. Fonda-Freedman oscillating circuit, employing tubes of conventional structure with or without special provisions.

The advantages and disadvantages of these four tube techniques are described below.

Conventional Tube Designed for UHF. These tubes are suitable only for the low-frequency end of the microwave band ordinarily. The problems are:

1. If the elements are far enough apart, the transit time is too long if the frequency is too high.
2. If the elements are spaced closer together to reduce the transit time, the interelectrode capacitance becomes too great.

3. If the elements are made smaller in surface to reduce the interelectrode capacitance, in order still to keep transit time at a minimum, then they are so small that they cannot handle sufficient power without becoming damaged or overheated. If they overheat, they can cause secondary emission themselves.

As a result, conventional tubes designed for very-high-frequency or ultra-high-frequency operation are a compromise useful only for a portion of the microwave spectrum. Their design is a compromise between transit time, interelectrode capacitance, and power-handling capacity. Such tubes are not very popular on frequencies higher than about 600 megacycles.

Klystron or Velocity-Modulated Tube. In the simplest form, this type of tube acts as a generator or oscillator by converting DC energy into high-frequency energy by slowing down or speeding up the electron flow. Resonance is made possible by the use of a special cavity type of resonating device. (These tubes cannot be completely discussed at present, particularly the better types, and they are quite costly; but this condition is expected to change in the early postwar period.) This type of tube is a positive grid and negative plate oscillator. Increasing the grid potential increases the electron velocity. The negative plate tends to repel the electron flow. Electron bunching with different velocities develops, which assists in developing the high frequencies required. This type of tube can be modulated in two different ways:

1. To produce FM, a change of plate voltage, already negative, changes the length of the path, while leaving the frequency of the oscillation of the electron about the grid constant. FM with wide-band characteristics becomes possible by applying a modulating voltage to the anode, sometimes called a repeller, if it is kept negative and repels the electrons trying to reach it after acceleration by the grid.
2. To produce AM, the modulating voltage is applied to both the positive grid and the negative plate. This permits varying the output amplitude without varying the frequency. As long as this compound modulation technique is employed, it will be amplitude modulation. If or when both the grid and plate are not used together for modulation, then frequency modulation will take place.

In addition to conventional biasing techniques, the velocity-modulated tube may differ from conventional tubes in that the grids are kept charged with a high positive value that in a low-powered tube may exceed 200 volts, while the anode is kept negative at a value exceeding 100 volts but substantially lower than the grid potential. The electrons then are accelerated by the positive grid and decelerated and even repelled by the negative plate. This accelerating action of the grid and repelling action of the plate provides the electron-bunching action which makes possible the generation of microwave frequencies that reach the high-frequency end of the microwave spectrum. A problem with this type of tube is the fact that any particular one is limited to a

certain frequency range determined by the amount of drift space within the elements. On frequencies higher than about 5000 megacycles, the dimensions become inconveniently small, while on frequencies lower than about 1500 megacycles, they become inconveniently large. They are convenient for frequencies between 2000 and 3000 megacycles, although they are quite efficient over a much greater range than that in either direction. Although this will doubtless be changed in the future, present tubes function on very low power, a common value being substantially less than a quarter of a watt output. However, even with such low power, they can provide very valuable communication on microwaves, because of the general advantages existing in that portion of the radio-frequency spectrum. Very successful two-way voice communication between 2500 and 3500 megacycles has been obtained with this type of tube technique, utilizing wide-band FM with a deviation ratio of nearly 300 to 1 by modulating the negative plate. The material and manufacturing cost favorably compares with conventional tubes. It should become increasingly popular when the development expense is written off and mass production is undertaken.

Magnetron. Another tube useful for microwave frequency generation is the magnetron. (Here again, the more efficient types cannot be discussed for the present.) In general, this tube is not ideal for two-way voice communication for universal application. It is more useful in forms of electronics involving special pulse techniques. In its simplest form, it consists of a cylindrical plate and an axial filament between the poles of a strong permanent magnet or an electromagnet. Electrons from the filament travel radially outward to the plate. The amount of radial effect depends on the magnetic field. The magnetron is not ideal for two-way radio communication and is only indirectly suitable.

Fonda-Freedman Method. In an effort to overcome the shortcomings of conventional tubes, the limited frequency spectrum of velocity-modulated tubes, and the limitations of the magnetron tubes, new methods have been developed which greatly simplify and reduce the cost of microwave equipment.

The author, in collaboration with a former engineering student of the University of Padua, Italy, has developed a method of generating, detecting, and modulating oscillating circuits with periods shorter than the transit time of electrons in vacuum tubes of conventional structure. Excellent results have thus far been obtained on all frequencies below 3000 megacycles with tubes such as the 6N7 and the 6F6, costing less than one dollar each. The upper frequency limits are still undetermined.

This development overcomes the problems ordinarily inherent in conventional tubes by making the transit time inconsequential. The

Federal Communications Commission Engineering Department is cognizant of this development where it may serve as a guide in postwar microwave-frequency allocations.

7 Antennas and Transmission Lines

The antennas on microwaves need be no different than for lower frequencies except that they must be cut for size. Since the dimensions become so small, they are usually considered in terms of a half-wave length in free space instead of a quarter-wave length against ground, although the latter is also conceivable.

The following dimensions prevail, but deduct 5 to 8 per cent from these figures for end effect, as the electrical wave length is that much longer then the physical length.

Frequency Megacycles	Wave-Length Centimeters	Quarter-Wave Length Inches	Half-Wave Length Inches
300	100	9.84	19.68
400	75	7.38	14.75
500	60	5.9	11.8
600	50	4.9	9.8
700	43	4.2	8.4
800	37	3.7	7.4
900	33	3.3	6.5
1,000	30	2.9	5.9
1,100	27	2.7	5.35
1,200	25	2.5	4.9
1,300	23	2.3	4.5
1,400	21.4	2.1	4.2
1,500	20	2.0	3.9
2,000	15	1.47	2.95
2,500	12	1.18	2.36
3,000	10	.98	1.96
3,500	8.55	.84	1.68
4,000	7.5	.74	1.47
5,000	6 0	.59	1.18
6,000	5.0	.49	.98
7,000	4.3	.42	.84
8,000	3.75	.37	.74
9,000	3.34	.33	.66
10,000	3.0	.29	.59
15,000	2.0	.20	.39
20,000	1.5	.15	.29
25,000	1.2	.12	.23
30,000	1.0	.10	.19

The transmission line for frequencies as high as 3000 megacycles may be good-quality coaxial cable, such as the 70 or 50 ohms solid or air dielectric cable, even though the loss begins to assume increasingly serious proportions per unit length with increase of frequency.

On frequencies higher than 3000 megacycles, coaxial cables of good quality can be used for very short lengths, but the losses become more serious. It is preferable to use air coaxial cable with metallic insulators instead of the usual insulated beads, or to resort to the use of wave guide. Whereas, on frequencies below about 400 megacycles, the copper transmission loss exceeds the dielectric loss, the opposite becomes the case as the frequency exceeds that point. This dielectric loss occurs in the medium or material used to hold the inner conductor concentric to the outer conductor of coaxial cable. Where coaxial cable is used, there is a tendency to use solid dielectric material, such as polystyrene compounds or polyethylene, instead of insulating spacer beads. On still higher frequencies, the solid dielectric material gives way to metalized insulators and conventional coaxial cable again. On the highest frequencies in the microwave spectrum, the use of a small rectangular or cylindrical wave guide becomes preferable.

A metalized insulator is a quarter-wave-length metallic support to hold the inner conductor concentric to the outer conductor of coaxial cable. Then insulated spacer beads or solid dielectric are not used. Instead of a steatite insulating bead every few inches in the coaxial cable, a metallic connecting support is secured to the inner conductor, which protrudes outward a quarter-wave length in material identical to the main outer sheath as shown in the illustration.

It is advisable to have these protuberances or "warts" spaced at unequal distances with respect to each other, such as 19, 23, and 18 inches. Instead of 2 to 6 inches as in the case of insulating beads, the spacing can be greater because of the greater rigidity and strength of metalized insulators. Unequal spacing prevents mechanical resonance or vibration in a moving vehicle when a lengthy transmission-line run may be necessary. The vibration will dampen out and be unable to pass more than one length. This type of coaxial line is also known as stub-supported line.

Insulated spacer beads as used in conventional coaxial cable are a bad source of loss. Dry nitrogen or dehydration systems have to be connected to the coaxial cable to reduce the tendency to sweat and become electroplated and eventually shorted out between inner conductor and outer sheath at every bead. By using quarter-wave metallic insulators instead of insulated beads wherever the inner conductor must be supported, gas or dehydration provisions may be dispensed with. Metallic insulators work on the principle that there will be opposite impedance every quarter-wave length, that is, if there is zero impedance at one end, there will be infinite impedance a quarter-wave length away for a particular frequency.

It is not feasible to use metallic insulators on low frequencies, since a quarter-wave length is too long. Likewise, it is not feasible to use them for frequencies higher than about 10,000 megacycles, as the length becomes too short. They must be correct in length for a particular frequency, or losses will become more and more prohibitive in amount. As mismatching occurs either higher or lower in frequency, a point of complete short is finally reached when a half-wave length is approached.

Parabolic Reflector. In addition to conventional methods of antenna radiation, the parabolic reflector, comparable with a locomotive or automobile headlight in shape and dimension, may be employed. This is possible because light or optical principles may be employed so far as directing the radiation is concerned. The reflector, or dish as it is more commonly called, is kept large with respect to the wave length. The larger this can be, the narrower the beam width will be. For example, a 12-inch dish might provide a beam 20 degrees wide, whereas a 36-inch dish might provide about 8 degrees width, on a wave length of about 10 centimeters. The beam width is dependent on the size of the dish and the frequency employed. Using a large dish and a very high frequency provides the sharpest beam.

The radiating element, which can be a half-wave dipole, such as that formed by a coaxial cable being brought out from the rear center of the reflector to protrude about a quarter-wave length in front, may consist of the inner conductor being bent or extended a quarter-wave length, while a corresponding quarter-wave length is made by the outer sheath.

To prevent any forward radiation without being sharply focused, the radiating element is reflected back by placing one or more reflectors of half-wave or comparable type in front of the radiating dipole.

Parabolic reflectors are feasible only on wave lengths shorter than about 15 centimeters and preferably below 10 centimeters, becoming incomparably ideal as the high-frequency end of the microwave band is approached. Therefore, various compromises may be employed for frequencies lower than those physically suitable in dimension for parabolic reflectors. These may be arrays of dipoles, as discussed in all radio literature. Half-wave-length elements may be provided in any number to act as radiators, directors, and reflectors to provide various desired beam widths.

The widths discussed pertain to the main lobe only. In addition, there are innumerable side lobes that provide communication short distances in any direction, but they are so much weaker than the main lobe that they can be ignored except for the first few hundred feet. Locally, within 500 feet or more, even beamed transmissions can be picked up at virtually any angle with usable strength. However, the main lobe ordinarily

This 36-inch parabolic reflector dish narrows a radio signal into approximately 8 degrees width. This is equivalent to increasing the power about 400 times because of the resultant concentration of energy on frequencies between 2500 and 3500 megacycles.
Below the circular reflector shown in the middle of the dish is the dipole fed by a coaxial or wave-guide transmission line. Its distance is approximately the same as that required for a beam of light shining against a polished reflecting mirror. Its beam width in space and intensity gain the same as is approximately the difference between an ordinary electric bulb and one used in a headlight.
Microwaves use light principles or radio principles, whichever is most convenient, both being available at any one time, to effect useful communication or relay service. Radio principles are valuable in straight clear stretches while light-beam principles are convenient for reflecting around obstructions.

exceeds by many times the power of all the other lobes combined, and ordinarily is the only useful component when the distance becomes more than a few hundred feet. These minor lobes are advantageous for such communication as along a highway or railroad track. Were they absolutely conformable to the main beam width, nothing would be heard outside the main beam until it diverged enough to cover the width of the highway or railroad. These minor lobes and reflections avoid such a situation and make possible excellent strong communication for a local region until the main beam lines up with the dimensions of the lane.

8 Wave Guides

The antenna is an approximate impedance-matching device between air and the transmitter via a transmission line. Any antenna good for transmission will also be good for reception. The same holds true for wave guides, where the same antenna may perform dual duty.

When sky-wave frequencies are employed, there are reflections from the ionized layers above the earth and multiple hops forward between the earth and the ionized layers. Their efficiency depends on the frequency employed and the height of the ionized layers. These layers vary in height throughout the day and night, every season, every sunspot cycle, and because of other influences as well. Their height is not suitable for frequencies higher than 30,000 kilocycles except for very brief erratic periods and then only on the end close to that threshold frequency.

Advanced radio circles considered that it should be possible to simulate the earth and the ionized layers by building up a provision which for radio communication purposes could serve instead of the perfect earth and the perfect unchanging ionosphere. On microwaves, the wave length is sufficiently short so that this could be possible by using rectangular or round pipe, or shapes that have a width of only a few inches. This turned out to be true and very successful. As a result, it is modern practice on super high frequencies, or on frequencies approaching that order, to develop antenna conditions right at the equipment directly if need be, or, if desired, by using a coaxial cable in conjunction with a wave guide.

The RCA Service Company has given permission for discussion of wave guides based on information compiled by J. R. Meagher and H. J. Markley, of its engineering staff. Their early and capable portrayal of wave-guide phenomena deserves great praise following outstanding research, prewar and subsequently, by scientists of the Bell Telephone Laboratories and the Massachusetts Institute of Technology.

Once the signal enters the wave guide, it can be squirted into space like a stream of water from a hose, if need be. The wave guide or offshoots of it can function as: (1) wave meters, (2) transmission lines, (3) antennas of various degrees of directivity, (4) impedance-matching devices, (5) transformers, or (6) slotted measuring and tuning lines.

As its name implies, a wave guide is a method of guiding energy from one point to another without radiating beyond its confines en route. A radio wave is considered to be electromagnetic in character as it travels through space. As an electromagnetic wave, it consists of an electric field and a magnetic field at right angles to each other. These both in turn are at right angles to the direction that the wave travels. It is therefore called a transverse wave. Neither field can exist alone. An electric field is dependent on or produced by a magnetic field. A magnetic field is de-

pendent on or produced by an electric field. That is the principle applicable to inductance and capacitance phenomena. The electric field at any point does not change as the wave proceeds. Instead, it changes merely in magnitude. The speed that a wave travels in a wave guide depends on the width of the guide and on the wave length or frequency. They reflect back and forth like light between two mirrors.

When the wave is exactly a half-wave length long, it approaches the width of the wave guide and attains an angle of 90 degrees. Then it ceases to make any further progress forward and merely bounces back and forth in the wave guide without going anywhere. The wave guide should have a width exceeding a half-wave length for whatever frequency is used, such as about seven-tenths of a wave length.

Wave-guide losses occur from the resultant electric current in the walls of the wave guide causing some resistance loss. Copper interior may have perhaps half the loss that brass might have on super high frequencies. This loss can be minimized by making the wave guide of good conducting material, such as copper or copper plating on a harder metal for better rigidity. The wave guide also loses energy as it reflects between the walls within the tubing. This loss will be greater near the cutoff frequency, that is, where it approaches a half-wave length and bounces back and forth more times during wave travel. If the wave-guide dimension is too great for the frequency, other losses occur. There is an optimum dimension or optimum frequency about twice the cutoff frequency. Increasing the dimensions to provide the optimum frequency may be uneconomical because of the limitations to physical dimensions and the increased material costs. Usually a compromise between cutoff frequency and optimum frequency is utilized, so that forward motion is satisfactory, and dimensional and cost considerations are not prohibitive. This has been found to be in the vicinity of seven-tenths of a wave length with possibly slight deviation from that figure in the future, as material availability and cost as well as changing dimensions for increased frequency operations may justify.

It is interesting to note that wave guides change the past conceptions of all conductors. For example, it is now correct to say that a power line, a telegraph wire, or a telephone line is actually a wave guide. It guides a magnetic field produced by the electric current sent along the wire from an origin to a destination. The ionosphere, the ether or air, and the earth together comprise a wave guide, but of erratic and constantly changing dimension. Modern wave guides hold the correct dimension.

If the wave guide is flared at the end in space, the radio waves can actually be squirted into space. Flared wave guides are known as wave guide horns or electromagnetic horns. No further antenna is then

necessary. To impress the energy into the wave guide, a dipole at the transmitter protruding into the wave guide, which may comprise a quarter-wave element against the wave-guide wall acting as ground, can be used. Radiation then starts at the transmitter and is guided into free space. Instead of propagating directly into free space, it can be terminated at an antenna element or squirted against a parabolic reflector for better directivity and energy concentration before being hurled into space.

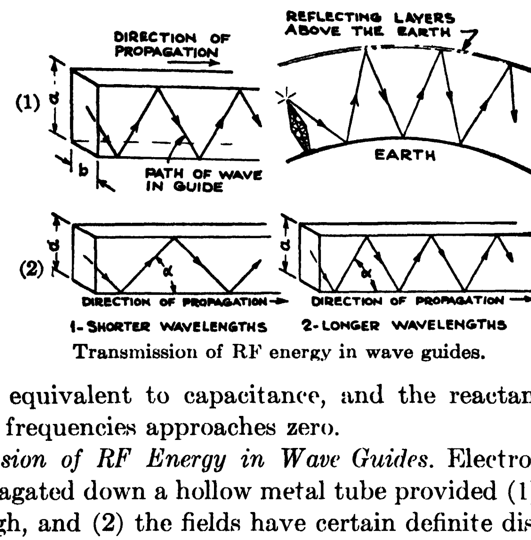
Innumerable combinations are possible. Many additional ingenious and simple methods will be disclosed as microwaves become more fully utilized in the future. For example, slotting the wave guide in various manners bearing correct wave-length relationship, or introducing metal having certain wave-length relationship, or otherwise changing the interior wave-guide dimension regardless how small, result in other interesting or useful phenomena.

Wave guides are useful to take over the function of a coaxial cable when the frequency becomes so high that coaxial transmission-line losses otherwise become prohibitive. To use a wave guide in the very-high-frequency band would require that it be substantially greater than a half-wave length, or more than 15 feet in width. On the medium-frequency band, it might have to be more than 1000 feet in diameter, whereas on very low frequencies it would have to be miles in diameter. A wave guide becomes increasingly useful as the frequency exceeds about 1500 megacycles. Below that frequency, good-quality coaxial cable may be preferable.

The development of wave-guide techniques has helped to explain why the line-of-sight theory for very high or microwave frequencies has been greatly exceeded in range in practice, although theoretically this should not have been so. It was a factor that was unknown previously and consequently overlooked. These wave-guide effects are what makes possible excellent and consistent communication in railroad tunnels, closed spaces, canyons, gorges, or mountainous country that block the line of sight optically. Such areas may have dimensions sufficiently great to form wave guides for frequencies much lower than the microwave band. This undoubtedly explains why 30 to 40 megacycle communication is possible beyond the unobstructed line of sight to provide many horizons of communication range. It plays no small part in extending communication along highways and railroads in country of rough terrain, or where the roadway was blasted out or cut out in hillside and mountainous recesses. Without an appreciation of these wave-guiding phenomena, it would have been perfectly logical to predict that such areas were completely unsuitable for communication. Very likely when communication

is unavailable in such regions, changing the frequency to one correct for wave-guide behavior would frequently correct that condition.

Wave guides are usually rectangular. Actually, only two walls are needed to assimilate the ionosphere and the earth. The other two walls are merely supporting surfaces to keep the first two in place. The greater the distance between the supporting surfaces, the more power can be handled. Two-way communication usually operates on low power, so that even the flattest wave guides with appropriate width can handle the load. Wave guides should not be dented or contain foreign matter, even so small a particle as a strand of steel wool, because that changes the interior dimension and therefore increases transmission loss. They may be broken, shot full of holes, or otherwise disturbed and still function,



Transmission of RF energy in wave guides.

since this is equivalent to capacitance, and the reactance of capacity at such high frequencies approaches zero.

Transmission of RF Energy in Wave Guides. Electromagnetic fields may be propagated down a hollow metal tube provided (1) the frequency is high enough, and (2) the fields have certain definite distributions.

Wave guides are essentially ultra-high-frequency devices, since the frequency must be high before a field can be transmitted (from a practical point of view) through a wave guide. A wave guide has a definite cutoff frequency, as determined by the cross section of the hollow tube, and will not operate at a frequency lower than the cutoff frequency. When the guide is half a wave length in width (dimension "a" in illustration), the wave reflects back and forth across the guide making no progress at all (hence cutoff frequency). It may be considered that the wave length of the RF energy must be short enough to fit into the cross-sectional dimensions of the wave guide.

The velocity of propagation (group velocity) of RF energy in a wave guide is slower than the speed in air. This is due to the fact that the wave does not travel straight through the guide but is reflected from wall to

wall. The length of the path that the wave travels is longer than the actual length of the guide. This action is comparable to the reflection of radio waves by ionized layers above the earth as illustrated.

The group velocity is dependent on the frequency and the tube dimensions (dimension "a" in rectangular guide in illustration). For a given size of rectangular guide, the group velocity—

1. Increases as the wave length becomes shorter, since there are fewer reflections from the wave-guide walls for a given amount of forward travel (see left side of illustration), but is always less than the speed of light.
2. Decreases as the wave length becomes longer (up to the cutoff frequency), since there are more reflections from the wave-guide walls for a given amount of forward travel (see right side of illustration).

A wave guide is a simple hollow metal tube having no central conductor. The losses are relatively low, since they will be produced mainly by the inner skin of the tube (which is of large perimeter and hence gives low loss). The inner surface should be clean and smooth. The outer surface can be grounded at any point since the RF penetrates only a thin skin of the inner surface. Sharp bends are usually avoided, and all bends and twists are arranged to prevent a change in mode of propagation, or reflections. Instead of a hollow metal guide, a solid dielectric may be used as a wave guide. The action in this case is comparable to light waves traveling inside a lucite rod. In general, the loss in a solid dielectric wave guide is greater than in a hollow wave guide.

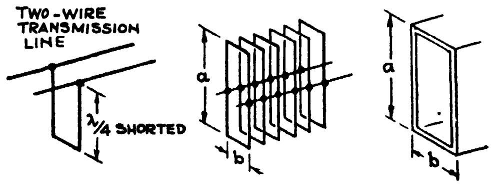
A wave guide cannot be conveniently treated like an ordinary transmission line. Wave guides must be approached from the viewpoint of an electromagnetic wave in a dielectric, using the same basis of treatment as that of radiation.

Wave guides may be rectangular, round, or oval. At the present time, rectangular wave guides are most simple and common; this discussion refers to rectangular wave guides for the most part, but much of this information can be extended to guides of other shapes.

The accompanying development of a simple-type wave guide is intended to serve as a means of bridging the gap between transmission lines and wave guides, although they operate on different principles.

A section of two-wire transmission line is illustrated here. A quarter-

(3)



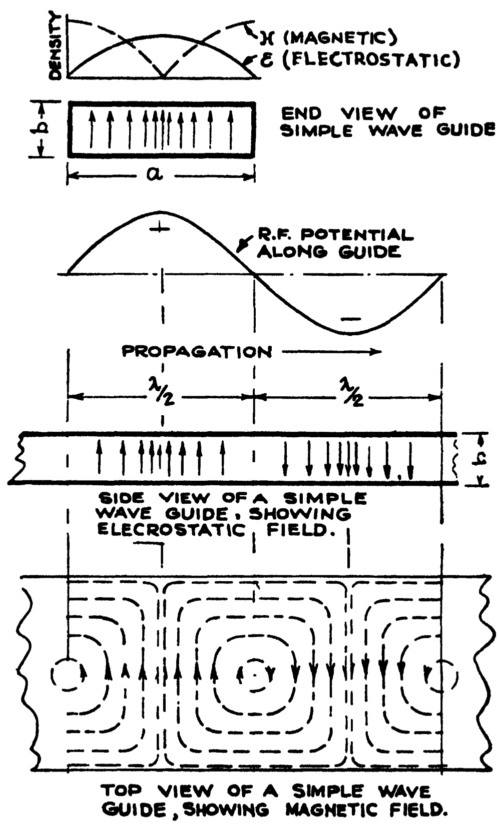
Transmission of RF energy in wave guides.

wave resonant stub has been added across the line. The ends of the stub where connected to the transmission line, will represent a high impedance many times higher than the impedance of any practical two-wire transmission line. As a result, the stub will have a negligible effect.

Suppose an infinite number of quarter-wave shorted stubs are added, resulting in a continuous pipe of rectangular cross section, or one type of wave guide. The minimum dimension of "a" is half a wave length (in order to propagate a signal), but it may be greater. The cutoff frequency depends on dimension "a." Dimension "b" is not critical except for voltage breakdown or the possibility of operation in a wrong mode.

For a simple rectangular wave guide, the electrostatic lines of force and density of distribution of the E & H fields are also illustrated here. The electromagnetic lines of force may be thought of as whirlpools in a plane, perpendicular to the electrostatic lines of force, traveling down the tube in the direction of propagation. A rectangular wave guide will

(4)

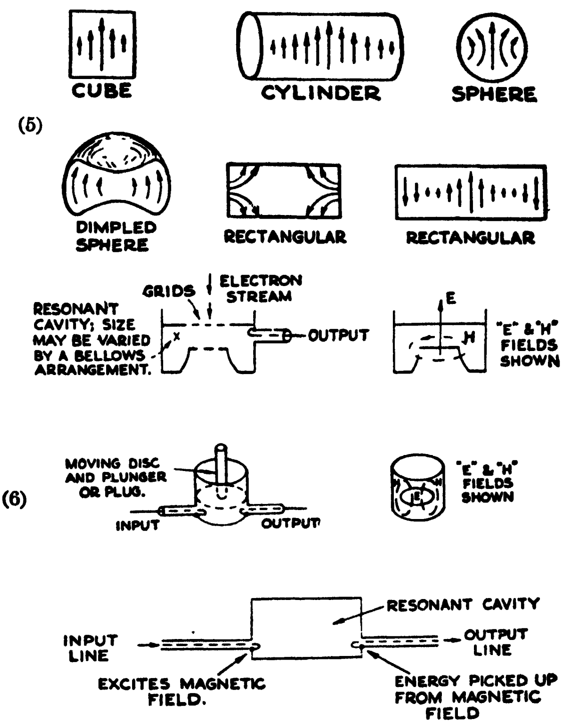


Wave-guide fields.

transmit satisfactorily if the component of the electric field tangent to the side surface is zero at every point on the surface.

A two-wire and a coaxial transmission line are shown with the magnetic and electrostatic fields indicated. A transmission line may be thought of as a guide for magnetic and electrostatic fields.

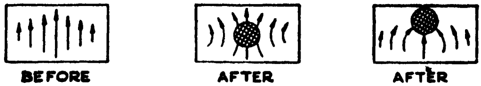
Cavity Resonators. Cavity resonators may take various shapes such as a cube, sphere, cylinder, sphere dimpled on top and bottom, or cylinder dented at one end (with ends forming grids as in an HF tube, for instance). Several possible types of cavity resonators are shown here. The electrostatic lines of force are also shown for one possible mode of operation.



Forms of actual cavity resonators.

The cavity (box) cannot resonate if it is too small for the wave length concerned. If the RF energy is the correct frequency for the cavity, high amplitude centimeter waves (fields) will propagate across and from top to bottom of the cavity.

For the purposes of explanation, a metal sphere is shown in a rectangular resonant cavity, with the E lines of force for this particular operation as shown in the illustration.

(7) 

Tuning slugs for cavity resonators. (Courtesy RCA Service Company.)

1. The slug shortens electrostatic (E) lines of force, hence the capacity is said to increase.
2. The magnetic (H) lines of force are normally weak at the center and are not appreciably affected.
3. The wave length increases (frequency lower).

If the slug is inserted at one side or the other, the result is as follows:

1. The slug shortens the magnetic lines of force (H), hence the effective inductance is said to decrease.
2. The electrostatic lines of force (E) are normally weak at the side and are not appreciably affected.
3. The wave length decreases (frequency higher).

Since the two positions of the slug, namely, in the maximum (E) field, and maximum (H) field, change the resonant frequency in opposite directions, it would be expected that a position where no change in wave length would result might be found.

9 Computations for Microwaves

The computations that follow are believed to be generally correct and are given for possible usefulness, but their complete accuracy for specific situations cannot be guaranteed because of relevant factors that must be known about each situation. These computations have been accumulated over a period of years and are the result of personal observations as well as of the opinions of individuals prominent in the microwave field and also interested in two-way radio communication.

GAIN OF AN ANTENNA

$$\text{Gain of an antenna} = k\,\frac{12.56A}{L^2}$$

A is area of antenna in square meters for its flat projection. If wave length is given in feet rather than meters, then A is in square feet.
k is a constant depending on the efficiency of antenna being about .65.
L is wave length in meters.

NOISE FOR 1-TO-1 FM RATIO ON FREQUENCIES EXCEEDING 1500 MEGACYCLES

$$\frac{e^2}{r} = 4kT\Delta f$$

where e = noise voltage at receiver input
r = characteristic impedance
T = temperature ambient
Δf = band width of intermediate frequency.

Field Strength for Amplitude Modulation within the Visual Horizon for Very High or Ultra High Frequencies

$$Mv = \frac{10.5\sqrt{P} \times G \times T \times R \times f}{D^2}$$

where Mv = field strength in microvolts per meter
P = power in watts
G = gain of antenna over conventional half-wave dipole
T = transmitting antenna height in feet
R = receiving antenna height in feet
f = frequency in kilocycles
D = distance in miles.

Beyond the visual horizon, signals fall off rapidly but not abruptly, doing so more rapidly than the inverse distance squared term of the formula.

Computing the Gain from a Focused or Beamed Antenna as Compared with Nondirectional Type

If the radiated power P crosses uniformly the surface of a sphere with radius R, then the power crossing every square unit surface will be

$$P_s = \frac{P}{4R^2\pi} \text{ (sphere)}$$

If the same power crosses the surface of that part of the same sphere which is cut out by a round cone with its top in the center of the sphere and with an opening angle α, then the power crossing every square unit surface of that part will be

$$P_b = \frac{P}{2R\pi\left(R - R\cos\frac{\alpha}{2}\right)} \text{ (beam)}$$

Therefore

$$P_b = P_s\frac{2}{1 - \cos\frac{\alpha}{2}}$$

Since R does not appear, this holds at any distance.

Power Picked Up at Receiving Antenna versus Power Leaving Transmitter Antenna

$$\text{Power at receiving point in watts} = Pt \times G\frac{A}{12.56 \times R^2}$$

where Pt = transmitted power in watts
G = gain of transmitter antenna array, or result of focusing by parabolic reflector
A = effective area of parabolic reflector in square feet
R = distance between two stations in feet.

VERY APPROXIMATE POWER AVAILABLE FOR WAYSIDE REFLECTORS ASSUMING NEXT POINT IS EQUAL DISTANCE TO PREVIOUS POINT

$$Pr = Pt \times G \times A \times \frac{w}{(12.65R^2)^2}$$

where Pr = subsequent point (power in watts)
Pt = transmitted power initially in watts
G = gain of transmitter array or reflector over simple dipole
A = area of wayside reflector
w = effective cross section of wayside reflector
R = range in feet.

This formula is probably less than indicated, since it does not make sufficient allowance for the angle of tilt of the wayside reflector with respect to another station that is not stationary, as in the case of railroad applications.

RECEIVED SIGNAL STRENGTH IN SPACE

$$\text{Received signal strength} = \frac{Ar}{12.56r^2} \times P \times G$$

where Ar = area of receiving parabolic reflector in squared meters
r = range in meters
G = gain of transmitter antenna
P = transmitted power in watts.

FORMULA FOR DESIGNING WAYSIDE REFLECTORS INSTEAD OF RELAY STATIONS

(Based on Preliminary Experimental Work of Fonda-Freedman Group)

$$P_a = P_s \times G_s \times \frac{a}{4 \times 3.1416 \times (r_1 \text{ plus } r_2)^2}$$

where P_a = power arriving at receiving device
P_s = total power radiated by source (if directional, to be multiplied by G_s, directional gain of source)
G_s = gain factor (if any) of source
a = equivalent area of receiving device
r_1 = range of source from reflector
r_2 = range of receiver from reflector.

Consideration 1. This reflector has a very sharp directional pattern that may or may not be fully useful. It may be very useful in communications between fixed points. It may be less useful between a fixed point and a mobile point which moves toward or away from the reflector, but not across the beam. It then may be necessary to use more reflectors to cover a proper number of positions of the movable station. However, these reflectors are of small size and feasible to provide.

Consideration 2. The direction factor changes with the frequency, so that in FM the frequency deviation should be kept small. This consideration is less important than the first one. With the usual deviation ratios, such as 5 to 1, there should be little practical change of reflected power. By adjusting the reflector for an average or mean frequency, it will be possible to reflect on the same beam two or more different but reasonably close frequencies.

CHAPTER TWELVE

TWO-WAY RADIO FOR RAILROADS

1 Radio Facilities for Railroads

Two-way radio in the railroad field provides communication that cannot be satisfactorily handled otherwise. Radio communication is not intended to replace existing devices developed during the course of a century of railroad experience. Complete two-way radio communication facilities for railroads can be tied into one integrated system, making possible the following combinations of communication and intercommunication, as desired.

1. From front to rear of same train, or vice versa.
2. From dispatching point to any train.
3. Between any two locomotives.
4. Between any rear ends of different trains.
5. Between the rear end of one train and the front end of another train.
6. Between yardmaster and train conductor or engineer.
8. Between conductor on train or on ground and the engineman.
9. Substituting during periods of wire prostration or signal failure or where such facilities are nonexistent.

Three types of induction radio and three types of space radio equipment are described here. One or more of these methods, conceivably all of them, may be useful in providing a comprehensive communication network for the major railroads that extend throughout the United States and engage in passenger and freight operations involving terminal areas, humpyards, classification yards, ferries, tugboats, and connecting motor vehicles. These methods are discussed in the order of their position in the radio-frequency spectrum.

Induction Method. In the induction method, the rails are used as primary signal conductors for very local ranges, and wayside wires for extended ranges. This method may employ very low frequencies, such as below 10 kilocycles, but likely to extend as high as several hundred

Two-way communication from administrative point to train. Test conducted by Bendix Radio Corporation on Baltimore and Ohio Railroad 156 megacycles AM. (Courtesy Bendix Radio Corp.)

kilocycles. Either amplitude or frequency modulation may be employed. The initial installations on the Pennsylvania Railroad by the Union Switch and Signal Company are an example. Future developments are not relying on the rails but will use frequencies and techniques similar to induction radio.

Induction Radio Method. This method utilizes the combined induction and radiation fields generated by radio-frequency signal energy impressed on wayside conductors such as power lines and telephone and telegraph wires, employing frequency modulation or amplitude modulation, usually at frequencies exceeding 50 kilocycles. Systems of this type are exemplified by the Halstead Traffic Communications Corporation induction radio system developed for railroad and highway applications. Recent developments by the Aerion Manufacturing Corporation for the Kansas City Southern Railroad and by the Union Switch and Signal Company for the Pennsylvania Railroad also favor this type of communication.

Space Radio Methods. Space radio methods as used on railroads may be subdivided into different frequency categories, each having wave-

propagation characteristics peculiar to a given portion of the frequency spectrum.

1. Medium-frequency (MF) systems are designated by the Federal Communications Commission as those which operate in the band from 300 kilocycles to 3000 kilocycles (wave lengths of 1,000 to 100 meters respectively). Ship-to shore and harbor radiotelephone systems, amateur, broadcast, aviation, and governmental activities currently utilize these frequencies.

2. Very-high-frequency (VHF) systems utilize frequencies in the range from 30 to 300 megacycles (10 meters to 1 meter). Two-way police, fire, forestry, public utility, and various emergency or special services operate extensively in this band.

3. Microwave systems employ frequencies exceeding 300 megacycles, or wave lengths shorter than 1 meter. This band extends to 30,000 megacycles, or wave lengths as short as 1 centimeter, of which wave lengths between 100 centimeters (1 meter) and 10 centimeters are definitely utilizable at present with likelihood of further utilization down to about 2½ centimeters in the future. The microwave band embraces the ultra-high-frequency (UHF) band from 300 to 3000 megacycles as well as the super-high-frequency (SHF) band extending from 3000 to 30,000 megacycles. The UHF band at present is utilized for military equipment, radio relay circuits, and experimental services. The SHF band is largely unutilized today except in the case of restricted military equipment and very special services. These bands present comparatively unlimited channel space for radio-beamed communications. The microwave band has wave-propagation characteristics that are noticeably quasi-optical in nature. There highly efficient directional antenna systems of small size may be used to advantage in directing and concentrating radio-wave energy along desired paths.

The more logical frequencies for permanent railroad use, on the basis of limited experience, appear to be the two extreme ends of the usable radio-frequency spectrum, namely the lowest frequencies principally dependent on the induction field and the very high frequencies or microwaves dependent on the radiation field. There the various radio communication needs of the railroads may be provided without conflicting with other essential radio communication services likely to raise an objection because of their prior channel occupancy.

Except where extremely costly equipment is selected, it may be financially as well as technically feasible to provide alternate facilities in the same railroad system. If one method should fail, the other could continue service. For additional railroad communication services, such as passenger radiotelephone on trains, additional channels might be required. In that case, the use of microwaves may become a necessity in order to provide sufficient frequency spectrum.

It is suggested that the equipment be kept simple and rugged, and with component-part power ratings two or more times the maximum that the individual parts are likely to encounter. It is also suggested that an alternate or auxiliary means of communication be provided to take

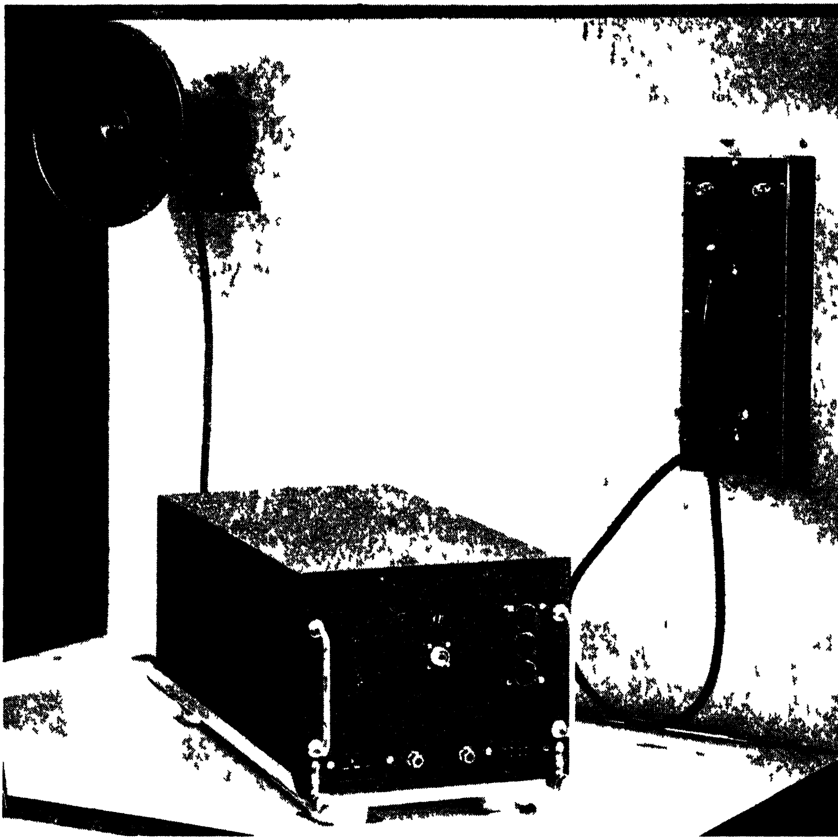
care of a temporary communication failure. This might be two equipments on one train, such as at the front and at the rear, or two methods such as induction and space radio.

Means for solving the vibration and shock problems are described in Chapter Four. The minimum provision recommended is ability to withstand a shock of 6G (where 1G represents the weight of the equipment). Equipment also should not mechanically resonate or vibrate at any frequency lower than 1400 cycles per minute.

2 Problems Peculiar to Railroad Radio

In applying two-way radio facilities on railroads, there are both advantages and disadvantages which may not exist in other radio services. In addition, these may vary to the extent that the factors involved may change from an advantageous condition to a disadvantageous one, or vice versa, as the train moves along the track for extensive distances. These variable factors are:

1. Changing terrain as the train travels along. Either the train or the fixed station may have extended or reduced communication ranges as a result.
2. Canyons which may either block radio communication or be helpful because of wave-reflection phenomena tending to increase the communication range.
3. Railroad curvature causing abrupt changes in the line-of-sight path which may be favorable or unfavorable depending on the local situation.
4. Tunnels which may block space radio communication on medium or low frequencies and yet be excellent for very high frequencies or microwaves because of wave-guide and reflection effects characteristic of such frequencies.
5. High speed of train movement which may be disadvantageous since it introduces vibration, noise, and radical changes in radio field strength.
6. Railroad trackage which is definitely advantageous for any form of communication, either induction or space radio, particularly in regions of otherwise poor ground conductivity, as it provides greater range and better signal strength. Trackage provides better performance than is possible for highway vehicles that may be traveling over dry, sandy, tarred, or cement roads, all of which are insulators. The tracks are valuable in extending effective railroad communication ranges, as salt water is valuable for marine communication, and high altitude for aeronautical communication.
7. Wayside wires, such as those provided by telephone, telegraph, or power lines, are advantageous. These are usually present along railroad right-of-ways. They vastly extend the communication range and are indispensable for induction radio. They are also markedly helpful for space radio beyond-horizon ranges but are not indispensable.
8. Limited lateral extent of the railroad right-of-way which is advantageous since communication need only be furnished for a narrow lane. This makes it convenient to use beamed radio transmissions, particularly microwaves, with great concentration of power, as well as guided radio using the wayside wires and induction methods. This assures privacy, power conservation, and minimum occupancy of a radio-frequency channel.



FM three-unit mobile induction radio set (engine cab, caboose, or emergency equipment) (1) Directional speaker for most convenient mounting, (2) rubber-cushioned mounted transmitter enclosed in dust cover Entire operating mechanism is of draw pull-out construction to facilitate servicing or replacement (3) Push-to-talk handset (Courtesy Aireon Manufacturing Corp)

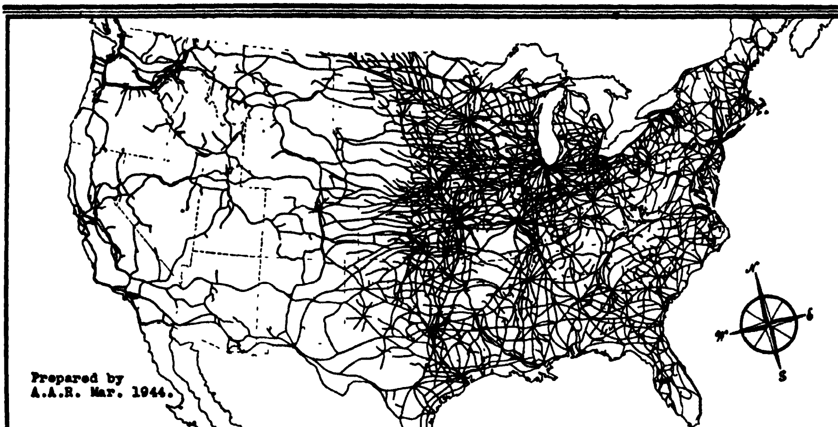
9 Electrical interference from rotating and sparking contacts of electrical equipment such as exists on electrified railroads or where diesel-electric locomotives are employed. This is disadvantageous and may be difficult to control except where frequency modulation and/or frequencies approaching the microwave spectrum are employed

3 Size of Railroad Industry

The leading railroad organization is the Association of American Railroads, representing virtually all the railroads in the United States, Canada, and Mexico There are 175 associate membership railroads operating 54,541 miles of right-of-way, in addition to the following full membership railroads as of November 1, 1943.

MILES OF ROAD IN THE UNITED STATES

ALL LINE-HAUL RAILROADS BY STATES (As of Dec. 31, 1942)



State	Miles Road Owned December 31 1942	State	Miles Road Owned December 31 1942	State	Miles Road Owned December 31 1942	State	Miles Road Owned December 31 1942
ALABAMA	4,906	KANSAS	8,479	NEW HAMPSHIRE	956	TENNESSEE	3,503
ARIZONA	2,215	KENTUCKY	3,534	NEW JERSEY	2,070	TEXAS	15,865
ARKANSAS	4,303	LOUISIANA	4,292	NEW MEXICO	2,598	UTAH	1,908
CALIFORNIA	7,824	MAINE	1,862	NEW YORK	7,644	VERMONT	918
COLORADO	4,480	MARYLAND	1,328	NORTH CAROLINA	4,628	VIRGINIA	4,205
CONNECTICUT	875	MASSACHUSETTS	1,748	NORTH DAKOTA	5,262	WASHINGTON	5,301
DELAWARE	295	MICHIGAN	7,176	OHIO	8,435	WEST VIRGINIA	3,763
FLORIDA	5,010	MINNESOTA	8,371	OKLAHOMA	6,018	WISCONSIN	6,540
GEORGIA	6,215	MISSISSIPPI	3,813	OREGON	3,383	WYOMING	2,008
IDAHO	2,742	MISSOURI	6,939	PENNSYLVANIA	10,088	DISTRICT OF COLUMBIA	34
ILLINOIS	11,777	MONTANA	5 105	RHODE ISLAND	189		
INDIANA	6,857	NEBRASKA	5,877	SOUTH CAROLINA	3,349	TOTAL	229,174
IOWA	8,906	NEVADA	1,828	SOUTH DAKOTA	3,988		

Full Membership	Miles of Road Operated 1942	Total Operating Revenue 1942
127 Class I railroads	227,664.08	$7,434,959,910
32 Class II railroads	2,238.09	15,671,655
13 Class III railroads	193.31	834,514
23 Switch and terminals	2,874.45	70,895,644
5 Electric railroads	513.58	7,059,606
1 Leased line	43.69	1,293,265
201 Total in U.S.	233,527.50	$7,530,714,594
5 Canadian railroads	39,762.38	571,673,926
5 Mexican railroads	9,907.29	54,157,552
211 Total	283,197.17	$8,156,546,072

PREWAR MILEAGES OF RAILROAD OPERATED IN VARIOUS NATIONS

United States (about 400,000 miles of trackage)	233,000
Russia	53,000
Canada	42,000
India	41,000
Germany	38,000
Australia	27,000
France	26,000
Argentina	25,000
Great Britain	20,000
Poland	13,000
Union of South Africa	13,000
Japan	11,000
Sweden, Italy, Mexico, each	10,000
Other nations, each much less than	10,000

FIFTY LONGEST RAILROADS IN NORTH AMERICA

Railroad	Road Mileage
Canadian National	23,560
Canadian Pacific	17,358
Southern Pacific	14,021
Atchison, Topeka and Santa Fe	13,137
New York Central	11,936
Chicago, Milwaukee, St. Paul & Pacific	10,820
Pennsylvania	10,761
Union Pacific	9,836
Missouri Pacific	9,756
Chicago Northwestern	9,729
Chicago Burlington	9,040
Great Northern	8,355
Southern Railway	8,244
Chicago, Rock Island & Pacific	7,802
National Railways of Mexico	7,334
Northern Pacific	6,873
Illinois Central	6,624
Baltimore and Ohio	6,174
Atlantic Coast Lines	4,990
St. Louis and San Francisco	4,863
Louisville and Nashville	4,744
Minneapolis, St. Paul & Ste. Marie	4,276
Seaboard Air Line	4,183
Missouri, Kansas, Texas	3,293
Chesapeake and Ohio	3,091
Denver, Rio Grande & Western	2,403
Erie	2,394
Wabash	2,393
Norfolk and Western	2,155
Pere Marquette	2,109
Gulf, Mobile & Ohio	1,968
Texas and Pacific	1,903
Central of Georgia	1,882
New York, New Haven & Hartford	1,838
Boston & Maine	1,824
New York, Chicago & St. Louis	1,688
St. Louis and Southwestern	1,616
Chicago and Great Western	1,501
Reading	1,424
Minneapolis & St. Louis	1,408
Lehigh	1,257
Western Pacific	1,194
Nashville, Chattanooga & St. Louis	1,090
Maine Central	987
Delaware, Lackawanna and Western	983
Alton	958
Spokane, Portland & Seattle	941
Kansas City Southern	935
Chicago & Eastern Illinois	911
Delaware and Hudson	856
Total	259,418

RAILROAD STATISTICS FROM 1930 TO 1940

	Highest Year	Lowest Year
Mileage owned	249,000 (1930)	233,000 (1940)
Locomotives	60,000 (1930)	44,000 (1940)
Freight cars	2,300,000 (1930)	1,600,000 (1939)
Passenger cars	53,000 (1930)	38,000 (1940)
Passengers carried	708,000,000 (1930)	435,000,000 (1933)
Freight tonnage	2,179,000,000 (1930)	1,229,000,000 (1932)
	(reviving to 1½ to 2 billion tons other years)	
Railway employees	1,500,000 (1930)	950,000 (1938)
	(with minor revival)	
Employee's wages	\$2,600,000,000 (1930)	\$1,400,000,000 (1933)
	(reviving to nearly 2 billion)	
Passenger revenues	\$730,000,000 (1930)	\$330,000,000 (1933)
Freight revenues	\$4,145,000,000 (1930)	\$2,485,000,000 (1932)
	(reviving to between 3 and 4 billions)	
Miles traveled by passengers	26,875,000,000 (1930)	16,368,000,000 (1933)
Revenue per passenger mile	2.72¢ (1939)	1.75c (1940)
Average miles per passenger	52 (1940)	35 (1932)
Freight revenue per ton mile	1.07¢ (1930)	.94¢ (1937)
Miles traveled by passenger trains	545,000,000 (1930)	380,000,000 (1933)
Miles traveled by freight trains	523,000,000 (1930)	368,000,000 (1932)
Human casualties (killed)	5,481 (1930)	4,362 (1939)
Human casualties (injured)	49,430 (1930)	27,263 (1938)
Grade crossing accidents (persons killed)	2,028 (1930)	1,011 (1931)
Grade crossing accidents (persons injured)	5,517 (1930)	3,697 (1933)
Total operating revenue	\$5,536,000,000 (1930)	\$3,138,000,000 (1933)
Operating expenses	\$3,993,000,000 (1930)	\$2,441,000,000 (1932)
Taxes	\$403,000,000 (1940)	\$241,000,000 (1935)
Net operating revenue	\$874,000,000 (1930)	\$325,000,000 (1932)
Net income	\$578,000,000 (1930) (profit)	\$121,629,000 (1934) (loss)
Ratio of operating expenses to operating revenue	77.06% (1932)	71.91% (1940)
Investment in road and equipment	\$26,095,000,000 (1931)	\$25,432,000,000 (1936)
Net capitalization	\$19,065,000,000 (1930)	\$17,600,000,000 (1940)
Stock on which dividends were paid	\$7,702,000,000 (1930)	\$3,119,000,000 (1933)
	(1932–1941 always below 4 billions)	

PEACETIME VERSUS WARTIME

	1930 to 1940 Best Year	1930 to 1940 Worst Year	1942 War Year
Passenger revenue	\$730,765,867 (1930)	\$329,816,306 (1933)	\$1,028,185,331
Freight revenue	\$4,145,015,015 (1930)	\$2,458,475,017 (1932)	\$5,944,344,072
Railroad employees	1,517,043 (1930)	958,280 (1938)	1,270,687
Employees' wages	\$2,588,597,979 (1930)	\$1,424,391,647 (1933)	\$2,932,069,581
Total operating revenue	\$5,356,483,927 (1930)	\$3,138,185,942 (1933)	\$7,500,000,000 (approx.)

4 Signals Versus Radio

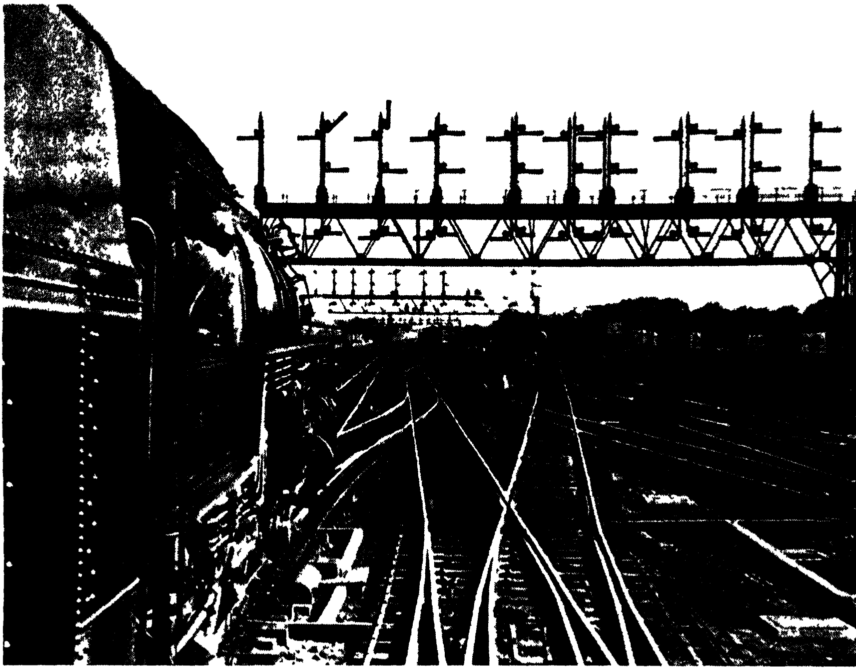
The public, the radio industry, and federal investigating groups have had their attention directed to railroad radio largely because of the inadequacy of signals from the viewpoint of safety.

The railroads, on the other hand, have a high regard for their signal systems but consider radio valuable only for additional tasks not now being performed, or for those that can be done better by radio than they are at present. The arguments against signals as well as for them are given here.

Argument against Signals. Radio and nonrailroad people feel that without the use of radio or induction signaling methods communication with moving trains has to be conducted almost entirely by limited visual signals or not at all. These signals may be the wave of a hand, a manual or automatic wayside signal light or semaphore, flags, lanterns, or flares. In some cases, torpedoes are attached to the track to be set off by a train passing over them. In extreme emergencies, crude but effective warning signals, such as burning blankets soaked in oil or a pile of wood set afire, have had to be used to stop a train.

The disadvantage of visual signals as compared with any type of two-way radio or induction communication is that only a few indications are possible, such as red, green, and amber lights, each designating a single word or two. Thus, signal lights may indicate STOP, CAUTION, or PROCEED. Their vocabulary is extremely limited, regardless of the type of signal employed. In most cases, except as visual signals may in the future be modified by radio and electronic developments, there is no way to prove that the signal is correctly viewed, understood, and acted upon except for the most costly and elaborate signal installations, which are relatively few in number.

Radio, on the other hand, has an unlimited vocabulary which may be handled at voice speeds (150 to 200 words per minute). Instead of a light signal signifying the single word STOP, radio can in the space of three seconds convey the following message, "Stop immediately, your eighth car is reported afire." Instead of a CAUTION signal, radio can convey, "Proceed with extreme caution, this train is stalled at ——. Trains on this track advise us of your location and arrival time." Instead of the conductor or trainman on the rear platform of one train holding his fingers to his nose and gesticulating with his hands and fingers toward a car on a passing train, which was observed to have a hotbox, a message can be radioed stating, "The rear truck of your thirty-first car has a hot-box which is smoking badly." The message can be sent as soon as the hotbox is sighted rather than wait until two mile-long trains have passed each other so that the men on the rear platforms are in position to signal



Elaborate signal system installed on the Baltimore and Ohio Railroad at a terminal. (Courtesy B & O Railroad.)

to each other (assuming the man in the rear has the word instead of the engineer), as passing trains separate at speeds around 150 miles per hour.

Argument for Signals. Signal and railroad companies feel that persons desirous of promoting the use of radio communication on railroads do not have entirely correct impressions of the adequacy and capability of existing railroad signal and communication facilities. From long experience with present signal methods, railroad men believe that the present signals operate satisfactorily despite their theoretical limitations. They point out that this is demonstrated by the fact that 35,000 to 40,000 trains run every day and that accidents caused by communications or signal failure are extremely rare.

Railroad men feel that the automatic feature of block signals is of the utmost importance. They claim that these signals work, and work correctly, millions of times without a failure and without human intervention. Furthermore, no one has to pick up a telephone and do anything positive; the signals deliver the message every time.

By proper combinations, moreover, railroad men feel that signals deliver a surprisingly large amount of detailed information—in other

words, that the signal system is not limited to the three words, STOP, CAUTION, and PROCEED. While they concede that signals may not be able to talk in the sense that telephones can, they feel that signals have the tremendous advantage of talking automatically and without human intervention.

What Railroads Concede about Radio versus Signals. It is obvious to the railroads that a technically satisfactory radio or induction communication system can deliver some messages which are beyond the range of visual signals. They concede the use of radio as an addition to the highly developed and virtually foolproof performance of present railroad signal systems. They also concede that their communication and signal systems can be improved by the additional and more varied messages which radio and induction communication makes possible.

One field of unquestioned usefulness for radio communication in railroad operation is universally conceded, that is, communication among the members of a train crew. Such communication adds increased safety in some directions and certainly avoids the considerable delay otherwise involved in transmitting information between caboose and engine. In these situations, railroad men feel that radio communication would definitely improve railroad operation, and that recent radio technical developments show promise of economical and efficient equipment for that purpose. Finally, they point out that the increasing use of radio on railroads depends not so much on technical details as on whether radio can increase safety or reduce operating costs, or accomplish both. They recognize that the technical details can be taken care of, particularly by the radio developments of World War II.

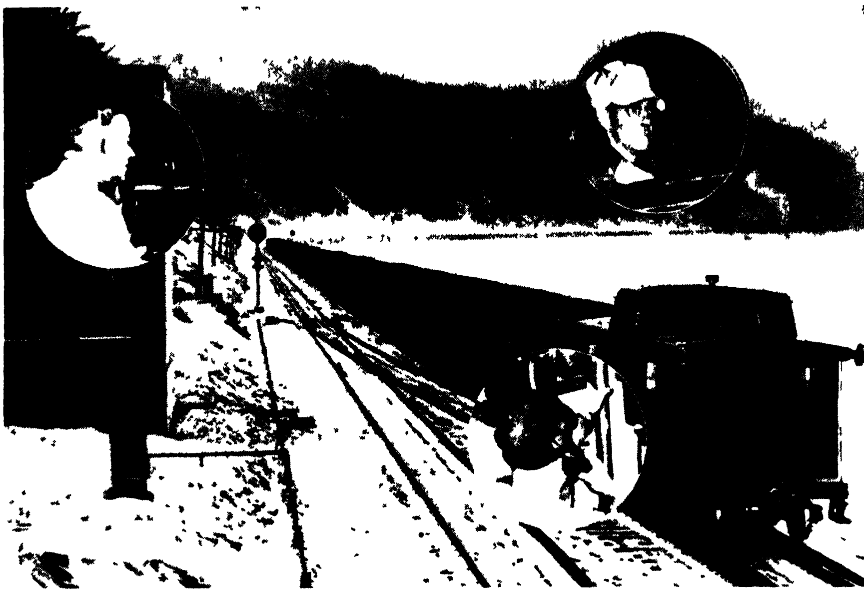
The railroad officials bring up another important point. They argue that the promotion of the use of radio or of some adaptation of electronics, such as radar, seems to be based on the assumption that a man who might run past a block signal warning him of danger ahead would not run past a radio or radar warning of the same nature. In their opinion, there is no sound basis for such an assumption, because, as is said in the railroad world, the greatest safety device is a safe man; and there is no reason to believe that the mere use of a radio device would of itself make safe men. They recognize that radio or induction communication would prevent wrecks in certain situations but *only if used correctly*, and there still is no assurance that the same man who does not use existing signals correctly would do so with radio.

5 Uses of Two-way Radio for Railroad Operations

Two-way radio is useful in the railroad field for end-to-end, terminal-and-yard, dispatching, safety, main-line, and miscellaneous communica-

tions heretofore either impossible or less satisfactory with existing facilities alone. Such communications may:

1. Exchange information front and rear of a train and thereby eliminate the need for applying the brakes from the rear of the train. This avoids the danger and expense of wearing wheels flat. Flat wheels, before replacement, may split the rails and cause derailment to a subsequent train.
2. Provide an oral check on how the air brakes hold and how long it takes the air to set the brakes after the application has been made at the head of the train.
3. Spot and pick up freight cars at plants.
4. Maintain a much closer relationship between the dispatcher, office, tower, and train crews.
5. Provide general communication from end to end of a train whether moving, standing still, or parted.
6. Enable the ranking executives and supervisory officials, whose duties and responsibilities confine them to their offices, to monitor railroad activities and be kept posted on general operations.
7. Eliminate or supplement reliance on visual signals alone that may be obscured by weather conditions, darkness, curvature of track, or tunnels.
8. Eliminate or minimize the need of hand signals or communications that otherwise require personnel to expose themselves to the elements or to walk the length of a train.
9. Acquaint the conductor and engineman of unsafe or unknown conditions en route.
10. Permit higher speeds in moving out of yards and terminals and increase of speed at the earliest opportunity, because information that the conductor, brakeman, and others are aboard will be received more quickly.
11. Permit faster movement out of sidings and resumption of speed, as the engineer will be more quickly advised that the switch has been closed and the flagman is aboard.
12. Avoid situations where a member of the train crew is left behind because of misunderstanding on the part of the engine crew.
13. Serve as an emergency or alternate communication facility in the event of wire prostration or inadequacy by assigning and utilizing such fixed and mobile radio facilities as may be available and necessary for the purpose.
14. Improve dispatching facilities so that available locomotives, trackage, sidings, and terminal facilities can handle peak loads of greater size in less time during seasonal or holiday peak freight and passenger traffic.
15. Reduce the tension of responsibility of a train crew, who otherwise might be uncertain as to what lies ahead or transpires elsewhere, allowing them to operate with the confidence of being cognizant of traffic conditions. In turn, the crew is aware that they can inform others as to any change in the movements of their own train.
16. Serve as a sales point in stressing efficiency and safety to prospective passenger and freight customers.
17. Divert and reroute traffic in the event of rail service disruption from any natural or accidental cause; also expedite the restoration of normal service.
18. Modify the operation, speed, arrival, or departure of a train once it has commenced its trip.



The three principal points requiring communication: (1) Dispatcher, (2) Conductor, (3) Engineman. (Courtesy Union Switch and Signal Co.)

19. Facilitate having relief personnel and equipment at the right spot at the right time.

20. Correct bottlenecks and confusing situations that may occur at a classification yard or terminal where a few locomotives may be handling thousands of freight cars daily.

21. Eliminate errors, relaying delays, and misunderstandings of third-party handling of railroad-operating information. The principals concerned should be able to communicate with each other by voice, so that the originator of a message knows the second party has received the message, understands it, will comply with it, and has no question or argument to make with respect to the message.

22. Enable key officials and individuals to be reached readily at any time for immediate decisions or authorizations.

23. Facilitate summoning or arranging for a doctor, nurse, ambulance, or hospital facilities at a point along the railroad in the event that a train passenger or employee is stricken ill or is injured. Radio may also be used to obtain temporary medical advice in a manner similar to the medico service of the merchant marine.

24. Summon train accident relief immediately and avoid the necessity of a member of the train crew walking several miles, in extreme cases, to reach a telephone or way station to report a train disaster.

25. Receive or transmit warnings of persons, animals, or stalled vehicles on the railroad tracks and information concerning landslides, snowdrifts, washouts, fallen trees, poles or wires, and the like, along the right-of-way.

26. Stop or slow down a train to pick up, discharge, or transfer passengers railroad personnel, or special equipment.

27. Cancel a stop or a slow-down if no passengers, freight, express, or mail are to be discharged or picked up at a scheduled stop.

28. Reduce the time required to sidetrack a train when a track must be cleared for an urgent rail movement.

29. Enable trains which have been stopped or sidetracked and are running slower or faster than their normal schedule to inform other traffic on the same track of conditions.

30. Exchange information instantly from train to train or from wayside to train, regarding hotbox, careening freight car, freight car afire, car door ajar, freight falling off, protrusions below a car, unauthorized persons on a car, or other abnormal conditions sighted.

31. Flash word if a wreck is sighted or conditions that might contribute to one.

32. Report or relay information concerning other trains, handcars, repair crews, and the like, along the route.

33. Enable train crews on trains ahead to send back information regarding weather and traffic conditions.

34. Permit quick and accurate information on snow conditions and prompt dispatching of snowplows to keep the track clear.

35. Maintain contact between sections of a train being made up at a starting point or temporarily separated when adding or detaching cars at a way station.

36. Report a signal failure or a break in landline facilities, so the exact spot may be quickly located.

37. Provide communication during power failure of fixed points.

38. Utilize portable equipment, such as the personalized walkie-talkie or handie-talkie units, to communicate with and between persons afoot or on handcars. Also, each train should have a self-powered (dry battery) emergency two-way unit, preferably located in a different part of the train from where the regular equipment is installed, as an alternative if front or rear equipment, or both, become inoperative. It can also be used by a man on the roof-walk of freight cars.

39. Co-ordinate instructions from the conductor at the hump tower to the locomotives that push freight cars up the hump to permit them to run downgrade to the desired track; also, aid in stopping or slowing down these cars by retarders or skatemen as may be desirable.

40. Pass the alarm and foil any attempt at sabotage or robbery on railroad property.

41. Maintain contact with key individuals on the train and elsewhere to check against human failures caused by exhaustion, illness, negligence, or incapacitation, thereby serving as a check against one of the great causes of rail disasters.

42. Deliver or transmit an important message to or from an individual on a moving train.

43. Arrange for addition or removal of coaches or Pullman cars, so that all passengers will have seats, or the hauling of excess-facilities will be reduced.

44. Arrange for fuel, water, or additional food for the dining car at some convenient point ahead with the assurance that the correct amount and type of supplies will be ready when the train reaches that point.

45. Eliminate dependence on way stations usually not open at night or closed at certain hours or during certain seasons, and therefore not available to relay instructions between a train and a pertinent fixed point.

46. Provide an oral check and comparison of train orders, particularly with respect to the prevention of head-on or other collisions resulting from stalled trains, a fast train overtaking a slow train on the same track, two trains moving on the same track in opposite directions, open switches, wrong switching, improperly reading a signal, or using a signal belonging to another track or train.

47. Enable the conductor to be in charge of his train in fact as well as in theory by providing oral communication between the members of the train crew. The engineer can report to the conductor the reasons for stopping, slowing down, speeding up, or for proceeding at other than normal conditions. The conductor can instruct the engineer to stop, resume speed, or slow down to spot a train at a convenient point. In some cases, it is feasible to spot half of a very long passenger train at a station platform, then move the train ahead so that the other half will be more ideally spotted, thereby saving the passengers a long walk with heavy luggage. Also, the engineer can be instructed to move a short distance, so that the train will not block a grade crossing or highway, and inconvenience road or street traffic unnecessarily. Also, the conductor could assure the engineer that he can safely back and block a highway or grade crossing without endangering any vehicle or pedestrian.

48. Notify railroad drawbridge attendants that a train is coming at a specified minute, so that the bridge will be closed. Also, bridge attendants might indicate that a vessel is near, and decision can be made as to whether to speed up to cross before arrival of vessel or slow down to cross afterward.

49. Co-ordinate the work of two locomotives, operating in tandem or where one is pulling and the other is pushing a very long train, when the one in front is out of sight due to curvature, grade, or visibility.

50. Enable the conductor and engineer to agree on where to stop for examination or repair of defective or questionable railroad equipment.

51. Intercept a criminal on a train or one who has escaped from a train.

52. Aid in determining whether certain passengers are on a train or possibly in a railroad station.

53. Summon police assistance, or fire-fighting, first-aid, or other emergency apparatus.

54. Eventually include making reservations ahead for Pullman seats, sleeper accommodations, hotel accommodations, travel beyond station destination, or for a conveyance or person to meet the train at the station.

55. Enable railroad and other supervisory officials to discover the characteristics of railroad personnel, so that the employees with the best records of safety and efficiency will be retained in, or advanced to, the positions where these standards are most essential.

56. Enable passengers and railroad personnel on moving trains to keep in touch with home or office, or with any point in the world through present telephone facilities or comparable public communication systems of the future. This is possible by a connecting toll service involving radio and landlines in a manner comparable with the already developed marine radiotelephone services described in Chapter 15.

57. Enable the Railway Express messenger on a train to notify stations ahead of large-sized shipments, so that extra-heavy articles can be handled promptly with additional help.

58. Handle important instructions or information between the postal authorities and the railroad mail cars.

59. Eliminate dependence on any physical connection between a train and a communicating point so far as communications are concerned.

6 Radio and Electronic Aids to Promote Railroad Safety

The extent to which the suggested uses for two-way radio communication might improve or assist in improving the safety of railroad operations is highly debatable among railroad personnel. It may depend on the adequacy of complementary or supplementary aids. The railroad safety record for twelve peacetime years is given here.

SAFETY RECORD FOR 12 PEACETIME YEARS

	Railroad Operations		Grade Crossings	
Year	Killed	Injured	Killed	Injured
1930	5,481	49,340	2,028	5,517
1931	5,099	35,656	1,011	4,657
1932	4,747	29,219	1,525	3,989
1933	5,019	27,294	1,511	3,697
1934	4,879	28,631	1,554	4,300
1935	5,107	28,080	1,680	4,658
1936	5,398	34,706	1,786	4,930
1937	5,350	36,693	1,875	5,136
1938	4,499	27,253	1,517	4,018
1939	4,362	28,119	1,398	3,999
1940	4,612	29,519	1,808	4,632
1941	5,086	37,811	1,931	4,885
12 years	59,639	392,681	31,745	87,947

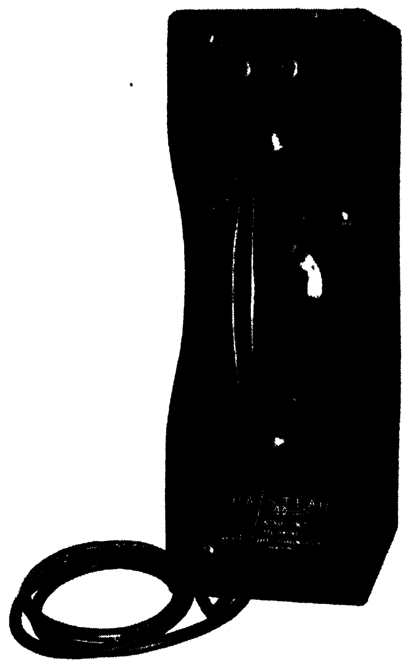
These figures include passengers, railroad employees from all causes, as well as persons crossing or trespassing on railroad property. Even though only a small percentage of these may have been fare-paying passengers, their status at the time of the accidents is not so important as the fact that human life is involved. Most of the grade-crossing accidents were largely motor vehicle accidents on railroad property. The toll may be duplicated at least partially in the larger railroad figures.

The railroad safety record compares favorably with other modes of transportation. This is particularly noteworthy since railroads normally maintain fast scheduled service in all kinds of weather and areas, night and day throughout the year. The figures are large only because the traffic volume is huge. The total death toll, passengers, employees, and trespassers combined, represents less than one for every half million passengers carried. Actually it was one fare-paying passenger per 336,000,000 miles of travel during 1943.

During the period these casualty figures cover, two-way radio communication was not available to assist in improving railroad operating safety. Any radio application during that time was of the most limited

nature, purely experimental in operation, usually in a yard communications activity.

In addition to the human toll there is also a loss of property and service disruption during accidents of substantial proportions, in the nature of wrecked or partially wrecked trains, damaged trackage, disturbed roadbeds, ruined freight, diverted patronage, and temporary tendency by the traveling public to refrain from nonessential travel. The railroads must maintain legal and claim facilities with procedure for investigating and settling these accidents or losses. When a person is killed or injured on railroad property, the railroad is usually confronted with expenses for settlement, lawsuits, investigations, doctors, hospital costs, ambulances, transportation of survivors, temporary shelter, and maintenance. Although settlements or costs may vary greatly, it is believed that the direct or indirect expense to the railroads can average $5000 per person killed and about $1000 per person injured. On that basis, an average of 5000 persons killed and 30,000 persons injured represents a cost to the railroad industry of $55,000,000 per year. Together with property damage and service disruption, the total can easily exceed $100,000,000 annually for an industry operating a 25 billion dollar plant with operating receipts exceeding 5 billion dollars annually.



Highway/railway control unit. When not receiving or transmitting, the check light blinks in accordance with pulses originating at headquarters. If this does not occur, communication has broken down and operator must be on the alert. (Courtesy Halstead Traffic Communications Corp.)

Radio and electronic aids may be useful even where signals exist, as a check against human errors that an engineman might make as the result of incorrectly reading or heeding signals, or reading the signal intended for another track, or maintaining speed approaching a signal on the gamble that it will change before the train reaches it.

The adoption of two-way radio in itself is an important step. When it becomes part of an extensive radio and electronic program for a rail-

The Sperry Rail detector car. An example of the use of electronics in railroad safety involving a combination of radio and magnetic phenomena. A generator on the self-propelled car introduces current into the rails. A visible or invisible defect in the rails produces flux variation as the car proceeds at a steady six miles an hour. These are amplified by radio vacuum tubes to a level sufficient to operate an automatic tape recorder inside the car and a paint gun beneath the car. Normally a bullet of white paint is shot automatically on the rail at the suspected point, while the tape recorder indicates a jog in an otherwise straight line on the slowly moving tape. More serious defects are painted red by manual means so that the repair crews will replace such rails first. In 1942, 90,000 defective rails required replacement, or one average hidden fissure in the rails per three miles. In 1944, these cars tested 162,866 miles of track, discovering 103,712 defects, or an average of one defective rail for every 1.57 miles of track. (Courtesy Sperry Products Inc.)

road, the opportunity to reduce accidents becomes much more probable. Electronic applications are almost unlimited in number, for the limit of the possibilities of the vacuum tube is the limit of the human imagination. This fact is the basis on which to proceed in striving for accident reduction to the vanishing point. Possible electronic developments that may be applied to railroad activities, some of which are actually in use or projected for use, are the following:

1. X-ray facilities to check flaws, fatigue, or breaks in metal before they actually cause accidents.
2. Radar, midar, or equivalent to reveal presence of animals, stalled vehicles, trains, landslides, fallen trees, or other obstructions on the right-of-way.
3. Phototube applications to use visible or invisible light to operate signals, such as those that are actuated by the shadow of a passing train.
4. Headlights of locomotives and tail lights of trains to operate alarms or automatic controls.
5. Sonic, supersonic, or microwave equipment along an entire railroad, so that the noise or contact of a passing train will actuate equipment. This in turn can be made to transmit information automatically along the railroad or cause a series of events to occur in a correct sequence.
6. Electron microscope to analyze materials or structural changes, with an amplification that can exceed 100,000 diameters.
7. Facsimile facilities on a radiotelephone communication channel to transmit by radio a printed page of illustrated or written material with reception on moving trains.

8. Panoramic cathode-ray tube reception to show the railroad radio-frequency spectrum occupancy at any moment.

9. Magnetic or inductive disturbances in the earth's magnetic field to reveal the presence of a moving train.

10. Sound detection equipment.

11. Vibration and shock analyzers.

12. Stroboscope applications for study of high-speed rotational equipment.

13. Induction radio or induction techniques with power circuits on electrified railroads for operating alarms and safety devices on trains and at wayside points, as well as for voice communication.

14. Announcing, paging, and intercar communication systems.

15. Radio-frequency heating equipment to shape, solder, or anneal metals. This prevents nonuniform application of heat, with too much at the surface and not enough in the interior.

16. Transducer applications to determine presence or movement by a change in capacitance or dielectric constant caused by a train, person, vehicle, or other obstruction on the railroad right-of-way. Also, if a railroad gate, tended or unattended, fails to function before the train reaches that point, an alarm can be given in time.

17. Manual or automatic weather information along railroad right-of-way. This can be a continuous and instantaneously operating system similar to that used in radio-sonde balloons now employed in meteorological services. Microwave equipment could send characteristic variations in signals which would be recorded at fixed or mobile points, showing conditions or variations of wind direction, wind force, air pressure, temperature, visibility, precipitation, and humidity.

18. Automatic warnings or announcements of train arrivals or delays.

19. Transit time and speed indicators.

20. Indicators to show that track is whole or continuous.

21. Correction and elimination of electrical and radio interference by cathode-ray or aural analysis.

22. Innumerable applications of vacuum tube circuits acting as electronic switches capable of performing any of the following functions as a basis of any necessary electronic device:

(a) Causing an action to occur as rapidly as a fraction of a microsecond that is, a fraction of a millionth of a second.
(b) Causing an action to occur as slowly as an hour or more.
(c) Cutting in or cutting out control circuits, electrical or mechanical devices with perfect precision within predetermined time limits.
(d) Causing one or more events to occur within any time interval.
(e) Slowing, speeding, stopping, or starting an action because of a related action.
(f) Special circuits to cause certain uniform or nonuniform phenomena to occur, to cease, to be delayed, or to accelerate.
(g) Timing generators to produce automatically timed or synchronized actions.
(h) Gate control circuits adaptable for use in automatically starting or stopping anything.
(i) Counting circuits of any upward or downward ratio which may be used to accept or reject any number of input pulses and pass along those desired for certain functions.

(j) Single-impulse control circuits that produce one event and then stand by to resume operation when required.

Prominent railroad officials define safety as being dependent on orderly operation. They feel that radio promotes safety because it facilitates orderly operation of a railroad.

7 Train Power Supply

The amount of power available or feasible to provide for two-way radio equipment on a moving vehicle is usually the principal limitation in the determination of how powerful a transmitter to use. Since the transmitting components require more power than those of the receiver, the type of receiver selected need not be limited because of power consumption. The exception may be in the case of low-powered microwave equipment or simple walkie-talkies where little difference exists in power consumption between transmission and reception.

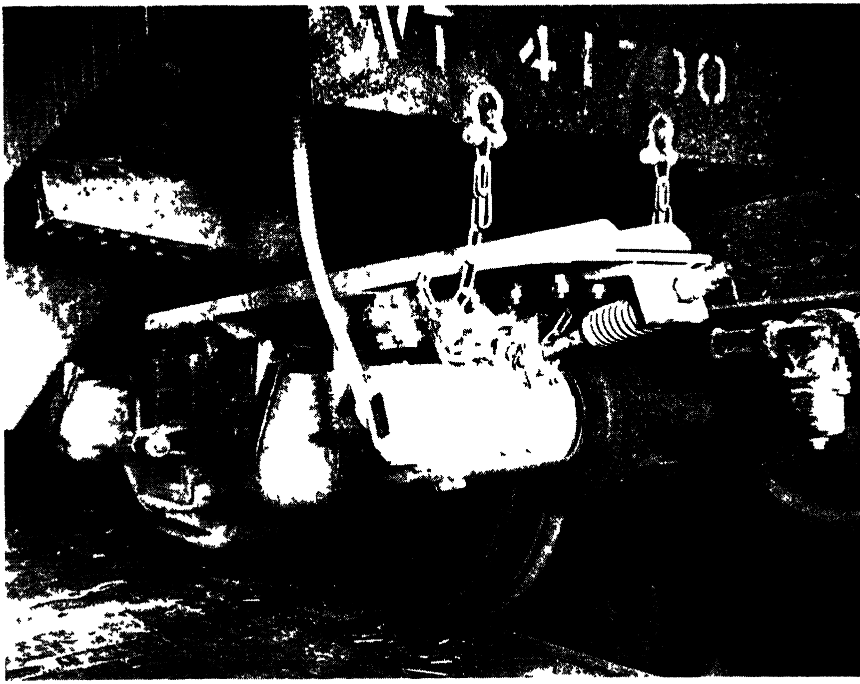
Modern two-way radio equipment is fairly compact and light in weight. It is not very difficult to compress radio units into a small space, when necessary, as in the walkie-talkie. Weight is seldom a factor in the mobile application, except possibly in small aircraft or portable uses. Power in each case must be adequate for the utilization required.

In addition to the limited and specialized types of power usually available on railroad rolling stock, there may also be a need for power to operate radio communication facilities or relay stations in areas where electric power is not readily available. Prior to the general adoption of radio, the caboose usually had no electrical power of any kind. Lighting in most cases comprised no more than a kerosene lamp. Yet the moment power is made available in a caboose for two-way radio equipment, a demand arises to provide electric lighting as well as power to operate small electrical appliances. If not permitted, the personnel may be apt to improvise and tap the power source on their own responsibility.

The following information concerning train power supply was furnished by the chairman of the Committee on Railroad Radio Communication Services of the Association of American Railroads, being the status in the fall of 1944.

Our mechanical people advise me that the following power facilities are generally available on trains. On locomotives—freight, passenger, and switch engines—there are three types of headlight generators, furnishing 32 volts and of capacities of 500, 750, and 1000 watts. A large majority of the road-engine headlight generators are of 750 and 1000 watts.

On passenger equipment in baggage and passenger cars, there are car-lighting storage batteries furnishing from 150 to 600 ampere hours. These batteries are in banks of 16 cells, and on the smaller and not air-conditioned cars provide 32 volts. On the heavier loaded cars 64 volts, consisting of two sets in series.



Generator on caboose to charge battery. (Courtesy Wincharger Corp.)

On a very few trains, and I believe generally this applies to diesel-powered equipment, there is a 110-volt AC train line. The number, however, is so small as to be practically negligible.

There are also a very few trains equipped with a small generating unit and train line, providing either 32, 64, to 110 volts DC. These are also very much in the minority.

Generally speaking, railroad radio equipment works from either 32 volts direct current or 110 volts 60-cycle single-phase alternating current. In the case of rolling stock, the latter will be developed usually from the headlight generator or from a storage battery source driving some type of electrical converter device. The storage battery may be charged either at the end of the trip or continuously, and be variably charged while the train is in motion by means of a charging generator similar to automobile methods. This generator may be operated by steam, belt, gears, or friction wheel. If operated by steam, it can be of a type and a size that will directly operate the equipment without batteries so long as a steam locomotive has steam available for this purpose.

Storage batteries may be preferable in all cases as a safety feature in the event that trains are not in motion for a considerable period, or if a steam locomotive should lose its steam for any reason. Under such

conditions, storage batteries make possible the operation of radio equipment for many hours without recharging.

In a desire to standardize radio equipment at all stations, some systems use types that function only on 110-volt 60-cycle single-phase AC. They then provide dynamotors, motor generators, converters, or vibrators to develop or convert any primary power source, whether it be 6, 32, 64, or 110 volts AC or DC, to the required power for the equipment. The user has the choice of standardizing the equipment and modifying the power supply, or leaving the power supply as it exists and having a variety of equipment types.

Radio equipment can be designed to work from any available voltage and current, either DC or AC, by utilizing components capable of such performance, by converting or rectifying the available electrical power to the correct type for radio operation. With the exception of 64 volts DC, the railroads can readily find power supplies already developed in quantity at reasonable prices, since they have been in use for many years in marine applications. (See Chapters Three and Fifteen.) Similarly aviation has had power equipment available for converting 12 or 24 volts DC to other forms. Police, fire, and forestry services have used 6 volts DC and 110 volts AC extensively as primary power sources. Such prior uses assure the railroads of availability of equipment at low cost.

The usual practice is to keep the transmitter tubes heated and lighted, ready for instantaneous transmission by depressing the microphone button switch. The receiver operates continuously, except that the plate voltage or some other part of the circuit may be made inoperative during actual transmission by means of a press-to-talk relay controlled automatically by the microphone control button. The constant load is for heating the transmitting and receiving tubes and to provide the high voltage for the receiver. All this usually totals a fraction of the maximum load required during transmission. The average station usually has occasion to use its transmitter a total of only a few minutes a day. Conversation is at the rate of 150 to 200 words a minute. Ten minutes' usage would cover at least 1500 words. The average contact is less than 50 words, including the call up, once a system is established and the experimental or testing period has passed. In terms of watt hours, the power consumption during transmission is very small. However, the power supply must be large enough to handle readily the intermittent transmitter load. It is safe to use the intermittent rather than the continuous rating of a power unit in taking care of the transmitter load. This makes possible the use of equipment which may be perhaps half the size and cost of continuous-rating equipment. Receiver power requirements, however, must be based on continuous rating. Since this is considerably less

than the transmitter requirements, an intermittent rating for a power unit to take care of the transmitter is ordinarily equivalent to a continuous rating and is more than sufficient to handle the receiver and standby loads. Many railroads are adopting 12-volt power supply for the caboose; others use 24 volts.

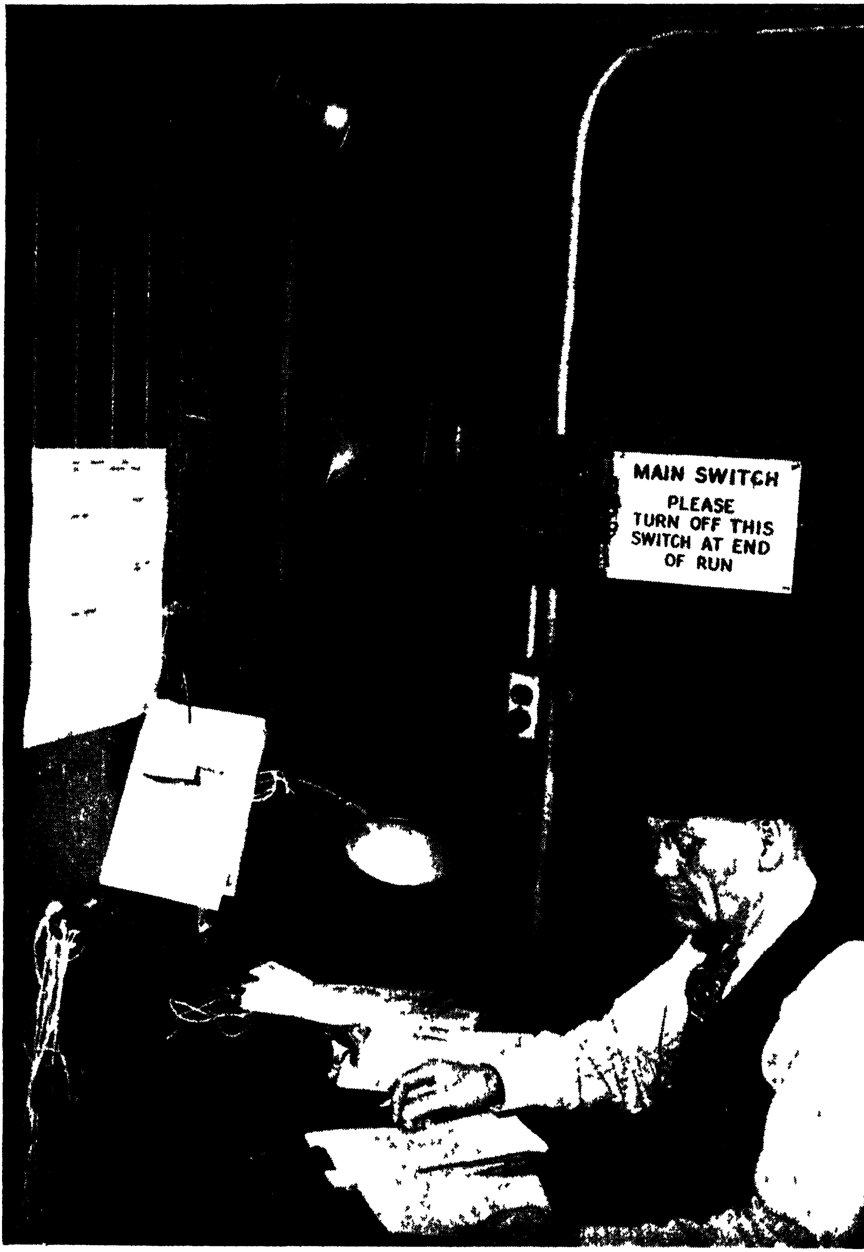
Power Consumption of Radio Equipment. Regardless of type, induction or space radiotelephone, the amount of power consumed largely depends on whether it is amplitude modulated or frequency modulated. AM uses nearly but not quite twice so much as FM for a given output transmitter rating, because it has to include an audio system much more extensive than that required for an FM system.

Both AM and FM equipments consume approximately the same power during receiving and standby. There may be a somewhat greater consumption for AM only because the larger audio system tubes draw extra filament current which more than offsets the reduced number of frequency multiplier tubes in the RF section. The usual receiving and standby load will be between 100 and 200 watts for the common types used in two-way service.

In the case of FM, during transmission with actual voice or full modulation, the load will be from 4 to 7 times the rated transmitting output. In the case of AM, it will be 7 to 13 times the rated transmitting output.

The power requirements do not increase directly as the equipment size increases. They also vary slightly between various manufacturers, depending on the number, size, and type of relays as well as tube types. Some systems are elaborately provided with various indicating lights which of course draw power. The wattage drawn as well as the output wattage will be higher when the power source, such as a storage battery, is of normal voltage or above. It will be less when the voltage is down, as when the battery is partially discharged. A storage battery has less energy available in subzero temperatures than it has during summer temperatures. However, small voltage variations can usually be disregarded, as the primary power-supply voltage is not extremely critical so far as its use in actual communication is concerned.

At fixed points, it is sometimes noted that a local power company supplies more power than the customer expects in order to increase the kilowatt-hour consumption. It used to be common practice to call a lighting circuit 110 volts. To guard against possibility of exceeding that figure, radio equipment frequently is rated at 115 volts. However, some companies have been feeding as much as 125 volts into the consumers' circuits, resulting in short-lived lighting bulbs and reduced ability of equipment components to stand up, particularly the vacuum tube fila-



Induction radio installation showing loudspeaker and power supply tapping off radio electrical system to provide desk lamp for conductor in caboose of Kansas City Southern freight train. (Photograph by Brooks Crummett Pictorial Press. Courtesy Aireon Manufacturing Corp.)

ments. It is an intelligent procedure occasionally to check the electric-line voltage which energizes the radio equipment, both at night and during the day, to see if the power company serves more or less than the expected voltage. If there is too much discrepancy, the power company should be notified; they can change the transformer tap or the transformer itself without cost to the user.

Typical Standard very-high-frequency radio equipment used in two-way radio communication draws the following approximate input powers in terms of wattage (that is, the product of the voltage multiplied by the amperage drawn from the power source to energize the equipment).

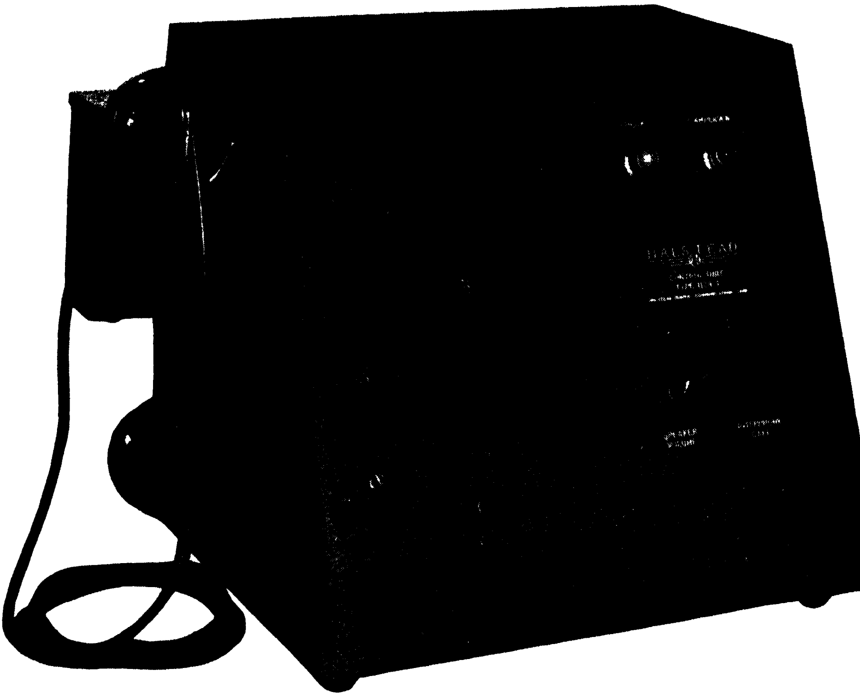
Size of Equipment Watts	Type of Modulation	Receiving and Standby Watts	Transmitting on Voice Watts
5	FM	50	90
15	FM	60	170
25	FM	60	180
60	FM	60	282
250	FM	225	1100
10	AM	45	130
100	AM	225	800
1000	AM	400	7000

8 Automatic Volume and Squelch Controls

As a train moves through various areas, it encounters nonuniform conditions for radio communication. These may be either normal, subnormal, or abnormal with respect to the ideal condition. The signal strength fluctuates and may result in erratic communication. This problem has been largely solved by the development of the automatic volume control, called AVC.

Merely by the use of a single additional tube, which frequently is the same tube that performs other duty in a radio receiver and therefore would be needed, automatic volume control provisions are possible. The AVC circuit is essentially an electronic rather than a mechanical means for turning down or turning up the volume control setting as may be necessary for uniform signal reception. It does this so rapidly and automatically that the human ear is unable to determine that fact and assumes that the transmitted signal is stable or that radio conditions are normal.

In the earlier days of radio broadcasting, it was common for broadcast listeners to be troubled by fading of stations, particularly at night. They would either leave the set alone and wait for the signal to revive or they would manipulate the volume control as necessary. A little later, the signal would get too loud, and the volume control would have to be turned down. It was a continuously erratic cycle. Later, modern receivers were developed that did not seem to suffer from such effects. The listener may not have realized it, but his new set had an AVC circuit in it.



Control and monitoring unit for use with railway radio communication equipment. This unit permits continuous loudspeaker monitoring of all conversations as well as operation of the radio equipment and interphone communications between other control and monitoring points. A checklight provides indication of operation of the constant checking system. It can also permit remote operation of radio equipment over telephone lines. (Courtesy Halstead Traffic Communications Corp.)

How AVC Functions. The last intermediate-frequency stage is usually where the automatic volume control circuit is made to vary the control grid in a modern superheterodyne type of receiver. At that point, it can by one operation control all the radio-frequency, intermediate-frequency, and frequency-mixer stages before it is fed to the audio amplifier of a receiver. The grid is biased more or less negative, depending on the amount of rectification taking place, by the output of the last IF stage feeding a diode tube. A strong signal causes more rectified voltage to be developed by the AVC diode tube, which is connected so that greater negative potential appears on the grid of the last IF tube. This in turn causes less electron emission to reach the plate of the last IF tube, so the signal becomes weaker. On the other hand, a weak signal causes the AVC diode tube to rectify less voltage, which results in less negative bias on the grid of the last IF tube. Thus, more emission reaches the plate, the receiver becomes more sensitive, and the received signal becomes stronger.

This action goes on indefinitely and endlessly. It occurs in millionths of a second, or much faster than the human ear can detect. It does this electronically without any mechanical wear. The AVC, therefore, by its fast, endless, and automatic operation makes it possible to have a stable signal at all times within reasonable limits. The only cause for malfunctioning of the AVC would be where the received signal has an unfavorable signal-to-noise ratio, that is, where the signal is weaker than the noise. This will be least likely to occur with frequency modulation.

Squelch Control. The automatic volume control is important in keeping the signal at a uniform level. Another great convenience, particularly in areas having high interference and noise levels and where these are intermittent or transient in character, is the squelch control. (Its operation is described in Chapter Eight.) In practice, the squelch control comprises a variable resistor, usually preset and mounted inside the receiver. A toggle switch on the control unit permits switching it on or off. Some noise is inevitable, but it is ordinarily weaker than the signal that is received when a transmission comes in. Because that happens to be the case, the output circuit of the receiver is made insensitive to noise of a level lower than that of a desired signal. The net result is that the receiver loudspeaker is absolutely quiet when no signal is coming through. When a signal is coming through, it is strong enough to override the squelching action so that only clear signals are heard. The action is automatic as in the case of the AVC.

The only thing to remember is that by squelching some of the receiver sensitivity, ordinarily the excess sensitivity, the receiver is then unable to respond to signals below a certain level, which means that some of the extreme beyond-horizon range is lost. When extreme range is necessary, merely throwing the squelch toggle switch to the OFF position will let the signal come in with the noise; or the noise can be minimized but not entirely overcome by turning the squelch threshold control closer to the point of operation by noise, so that only spillover noises come through. When extreme range and sensitivity are necessary, it is sufficiently important for the listener to tolerate some noise. Systems are designed to provide sufficient signal strength and range with the squelch switch in the ON position so that such action is not ordinarily necessary. In effect, the receiver is deaf to noise and alert to desired signals.

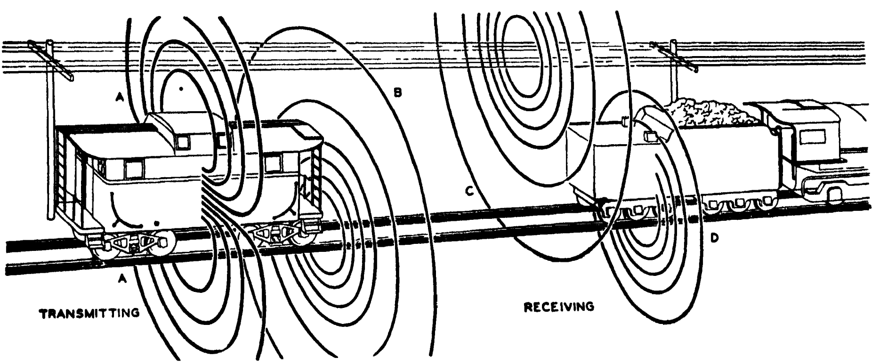
9 Union Inductive System

This system is a development of the Union Switch and Signal Company to perform the functions normally expected from two-way radio. It employs the principle of energy transfer by inductive coupling for the transmission of telephone conversation between locomotives, cabooses

and wayside points. The following details largely distinguish the Union inductive system from any other type of induction system suitable for train communication:

1. The rails, ground, and adjacent line wires are all utilized for transmission of a carrier current. A small amount of communication is possible from the track alone.
2. The carrier current is received on vehicles by induction through receiving coils placed in inductive relation to the rails.
3. In transmission from vehicles, the carrier current is fed into the rails and line wires by conduction and induction.

Like the other types of induction systems discussed in this book, this system has been carefully designed to comply with the low-power rules of the Federal Communications Commission. Compliance with these



Union Switch and Signal Company Induction system as used on the Pennsylvania and other railroads: *A* shows induction field developed by the caboose; *B* shows existing wayside telephone and telegraph landlines; *C* shows effect of the track; *D* shows pickup by locomotive from wayside wires and track. This is the only system that claims dependence on track as well as wayside wires. The manufacturer distinguishes it as an inductive, rather than induction radio system. (Courtesy Union Switch and Signal Co.)

rules eliminates the necessity of having either the operating and maintenance personnel or the equipment subject to federal licensing.

The Union inductive system is the result of a series of developments covering a long experience period commencing with cab signaling equipment. It is designed to have minimum radiation beyond the railroad right-of-way. There were early attempts to use voice current on the rails themselves. This was found to be impractical because of high noise levels and interference with adjacent telephone lines also using voice frequencies. These difficulties were largely overcome by the use of voice modulation on a very-low-frequency carrier current such as 5700 and 7700 cycles per second employing amplitude modulation. Several installations are still performing usefully for substantial distances in railroad

operations. A disadvantage was the need to insulate the trucks of rolling stock from the chassis and to bond the track because of the low frequency and high noise levels characteristic of amplitude modulation.

At present, the Union inductive system uses carrier frequencies selected in the region between 5 and 250 kilocycles. Frequency modulation is employed except with carriers lower than 10 kilocycles where amplitude modulation is still advisable due to the limited over-all frequency spectrum. The frequencies employed for a particular installation may depend on whether any other carrier communication is already in use on the adjacent wires along the right-of-way. At the present time, the Bell Telephone Company employs the following carrier systems on open-wire lines:

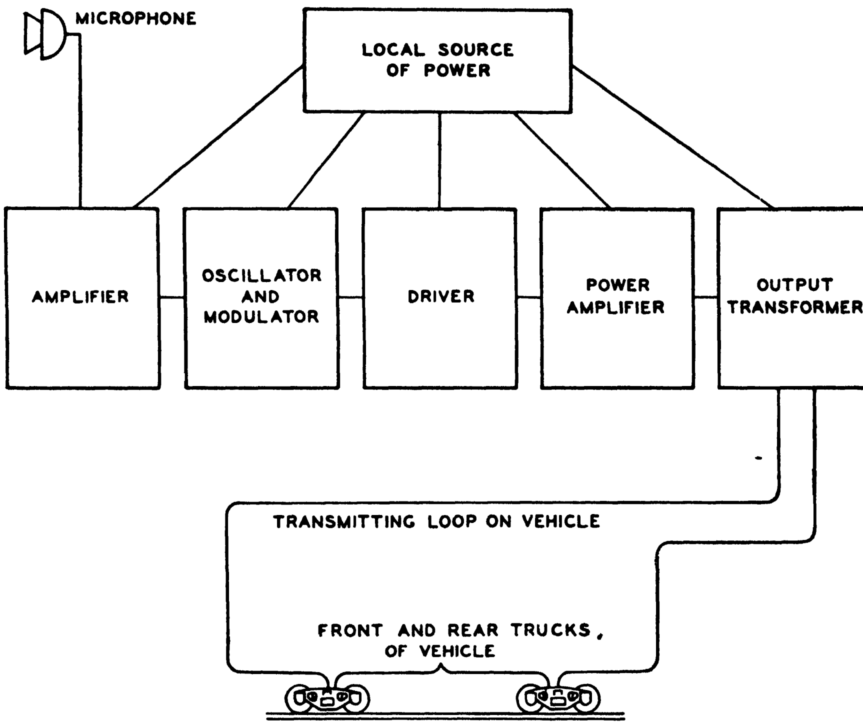
"H" system—4000 to 7150 cycles in one direction.
7150 to 10,300 cycles in opposite direction.
"C" system—4500 to 16,000 cycles in one direction.
16,500 to 30,500 cycles in opposite direction.
"J" system—36,000 to 84,000 cycles in one direction.
92,000 to 143,000 cycles in opposite direction.

In addition, the Western Union Telegraph Company employs carrier current systems for telegraphy having three different upper-frequency limits, namely, 7, 15, and 30 kilocycles per second. On this basis, frequencies exceeding 143 kilocycles should be free of telephone or telegraph open-wire interference. In practice, all the frequencies indicated may not be in use along a particular railroad division, so that frequencies lower than 143 kilocycles can often be safely employed.

When the Pennsylvania Railroad adopted the Union inductive system for the Middle Division between Harrisburg and Pittsburgh, the frequencies chosen were 88 and 120 kilocycles; the latter was subsequently changed to 144 kilocycles. This particular contract involved 275 locomotives, 90 cabooses, and 6 wayside stations spaced about 40 miles apart, extending over the Alleghany Mountains and over part of one of the busiest railroad routes in the world. An average of one freight or passenger train travels that route every seven minutes throughout each twenty-four hours. The equipment can be adjusted over a wide frequency range should it ever be desired to change frequency in the future.

Principles of Transmission. An alternating electrical current in a conductor produces fields of two kinds: one known as the radiated field, and the other as the inductive field. The radiated field is used for the transmission of radio, and it is propagated continuously away from the conductor. The inductive field is used in the Union inductive communication system. In the neighborhood of the conductor, the inductive field is very much stronger than the radiated field. It is sometimes called "the field

that stays at home." It expands out from the conductors when the current in the conductor is increasing and collapses into the conductor when the current is decreasing. This expansion and contraction of the field has the effect of producing voltages and currents in other conductors enclosed by it, thereby transferring electrical energy from one conductor to another without metallic connection. This action is identical to the

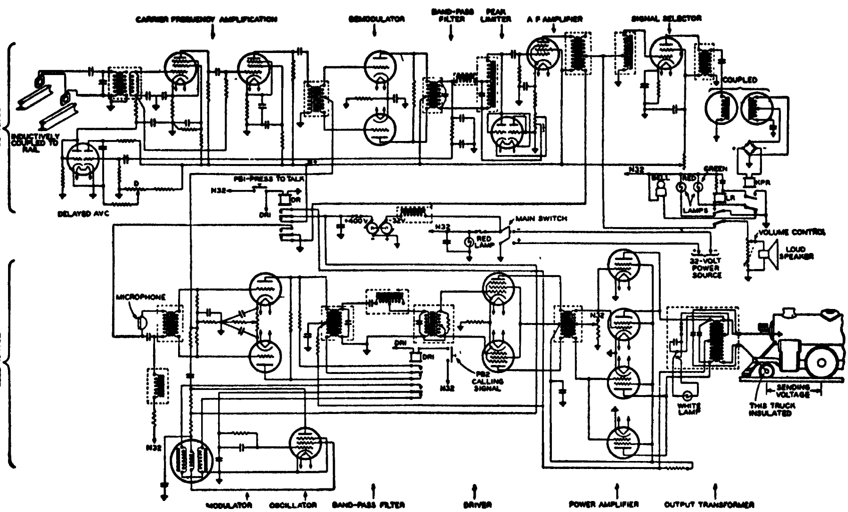


Union induction train transmitter. The transmitter output is fed to an output transformer box containing a transformer and the necessary tuning equipment to match it to the transmitting loop. This loop includes the wheel base of the vehicle. On caboose it is connected to both the journal boxes on the extreme axle at the two ends of the vehicle. (Courtesy Union Switch and Signal Co.)

principles of an alternating-current transformer, in which the flow of current in the primary winding produces an inductive field by which energy is transferred to the secondary winding, which is electrically separated from the primary. Any field produced by an alternating current in one circuit and linked with another circuit produces this transformer effect and sets up a voltage in the second circuit.

Caboose and Locomotive. Consider a caboose and a locomotive on a track with an adjacent lead of wayside wires. Assume that transmission

is from the caboose and that a loop connected to the output circuit produces a magnetic field that threads the body of the caboose. A large part of the field envelops the track under the caboose and induces in the track a voltage in exactly the same way that the current in the primary of a transformer induces a voltage in the secondary of the transformer. A small variable part of the field also links the line wires and produces a voltage in them.



Circuit diagram for two-way train-carried equipment with signal selector

Amplitude modulation type inductive equipment designed for 5.7 kilocycles and higher. To transmit, the microphone output is applied to the grids of the modulator stage in push-pull while the carrier energy is applied to the grids in parallel. The resulting modulation in a perfectly balanced circuit does not contain the carrier but does have in it principally the two side-bands. The remaining carrier and the lower side-band are removed by the filter which follows, so that the tubes which drive the power stage are practically energized by the upper side-band only. The output stage consists of four 6L6 tubes in parallel push-pull and is connected to the sending loop or direct coupling circuit which extends from the engine pilot truck wheels through the rails to the drivers and back through the engine frame. (Courtesy Union Switch and Signal Co.)

The voltage induced in the track results in a current in the track, which travels in the same direction in both rails and returns through the ground and the rails on the other side of the caboose. The rails together with the ballast leakage to ground and the ground return circuit constitute a complete loop, and the current in this loop also produces a magnetic field. Some lines in this magnetic field surround the line wires on the adjacent pole line. This fact makes the wires on the pole line the secondary of a transformer, of which the track loop and the transmitting loop are co-operating primaries, so that another inductive transfer of communications power takes place.

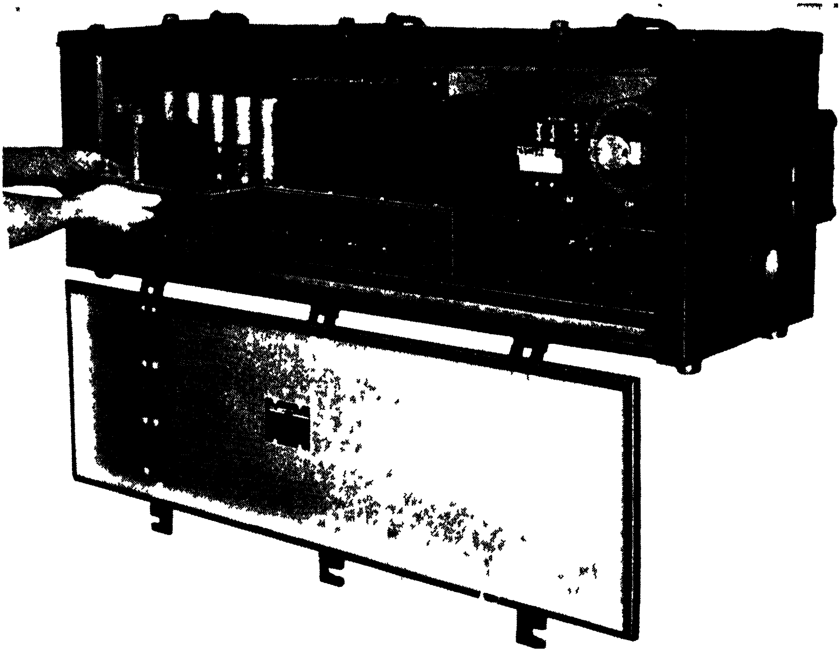
The line wires have a high resistance so that the voltage produced in them results in a very small current. This current, however, is useful at a much greater distance than the track current because the attenuation is very much less. The attenuation in the track is great because of the leakage from track to ground; the attenuation in the line wires is small because the leakage through capacity to ground is very low. For the Middle Division of the Pennsylvania Railroad, the drop in a lead of line wires was found to be about 0.4 decibels per mile. This low attenuation enables the carrier current to travel long distances with small diminution, thereby making possible long-range transmission from the caboose over the line wires.

Near the locomotive, which is the receiving station in this case, there is a magnetic field produced by the current in the line wires and partly surrounding the track rails. This magnetic field produces a voltage in the rails, which again results in a current in a track loop similar to the one described in connection with the caboose.

The current in the track loop is accompanied by its own magnetic field, a part of which links the receiving coils shown on the tender deck of the locomotive. In this case, the track loop is again a primary, the receiving coils are the secondary of a transformer, and the voltage produced in the receiving coils is amplified and demodulated in the receiver. The resulting audio-frequency currents are used to energize a loudspeaker or the receiver of a handset.

In making important use of the track loop, it is advantageous to have the rails bonded, particularly so on the lower carrier frequencies. With the use of higher frequencies in the latest systems, the bonding while useful is less important.

Any conductors that parallel the track and are not too far away from the track help in transmission and reception. The nearer the leads of wires, the less power is required for a given range of transmission. In practice, the wires will be usually between 20 and 100 feet from the vehicle on the track. Ranges discussed here are based on the assumption that the wires will be between 100 and 150 feet away from the track. Transfer of energy from rail to line wires and back from line wires to rail through the inductive field is effective with substantially all conductors which may exist in the neighborhood of the rails. Trolleys, catenary structures, telephone, telegraph, signal control wires, and even farm wire fences in the neighborhood of the right-of-way are useful for transmitting the carrier currents. Breaks in the line wires do not interfere with operation unless there is a substantial gap in all of the conductors at the same location. In cases where all possible wayside conductors are absent, a single line wire can be installed to assist transmission. This may be of



Union FM train-carried equipment. From left to right the three frames can be identified as the receiver, transmitter, and power supply. (Courtesy Union Switch and Signal Co.)

the simplest possible construction. The wire may be run on the ties, or a buried wire may be used for short distances in case the wire cannot be run above the ground.

Wayside Station or Office. In the transmission from a fixed point, the coupling to the line wire may be more direct. In that case, the output of the transmitter is usually connected with one terminal to a line wire or a pair of line wires, and with the other terminal to the track Instead of direct connection to the line wire, it is possible and sometimes practiced to connect the output terminals to two short line wires, each spanning two or three poles and connected at the far ends to the track. This provides adequate inductive coupling between such a loop and the line wires for transmission, and thereby makes it unnecessary to have metallic coupling to circuits already existent, should that be inconvenient.

In receiving at a station, many different methods of coupling may be similarly used. The coupling for reception may be to a line wire or a pair of line wires, directly or through a transformer connected between the line wires and the track, or even across a resistor in such a connection, or across the impedance of a short length of rail near the station.

The effective range of this system without exceeding a field strength

of 15 microvolts per meter at a distance equal to the lambda over 2 pi rule, or 157,000 divided by the frequency in kilocycles, is 50 to 100 miles between vehicle and wayside point.

In the case of vehicle-to-vehicle stations, whether on the same or different trains, the range is much less because there are four energy transfers instead of two, namely:

1. Transmitting loop to rails.
2. Rails to adjacent line wires.
3. Line wires to rails.
4. Rails to receiving coils.

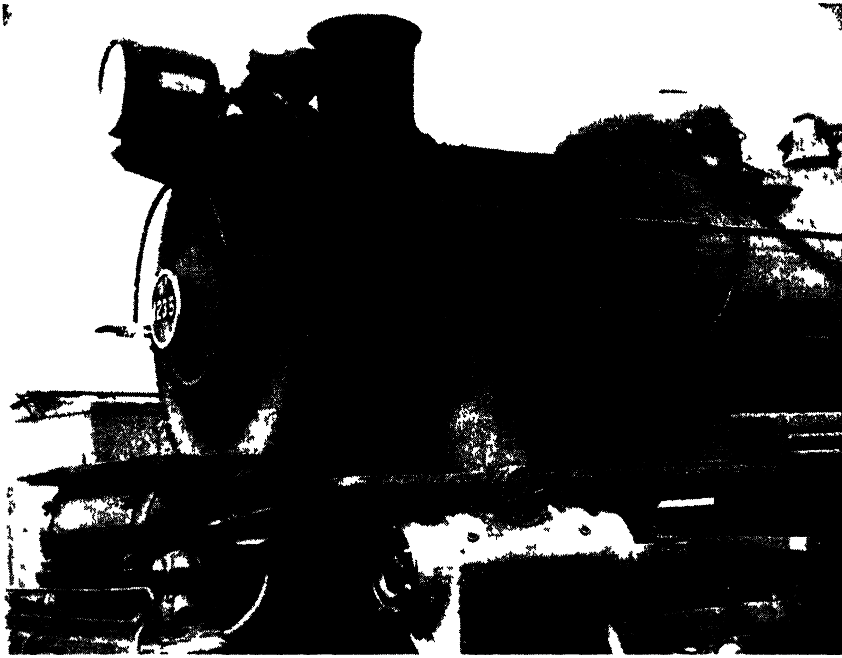
Each of these transfers results in energy loss, so that the range is approximately 10 miles train to train, which is adequate for the needs of railroad service.

Between two office points, ranges can be greater than from wayside station to vehicle or vehicle to vehicle for a given power, as superior coupling is possible. Signal intensity falls off sharply with increasing distance between wayside wires and vehicle. For mobile applications, therefore, range is more a function of distance between track and wayside wires than anything else. Some railroads are admirably suited for inductive communication, while in a few cases, chiefly in canyon and mountain regions, where wires leave the railroad right-of-way to follow air-line or short-cut routes at times, a special wire must be provided or space radio must be employed.

Offsetting the disadvantage of requiring the presence of wayside conductors, which usually is the case in the railroad field as a whole, are numerous advantages for railroads. These may be:

1. Independence of railroad curvature or grade obscuring natural space communication paths.
2. Relatively close confinement of the transmission to the right-of-way with minimum likelihood of reception or interference at distances from the wayside wires.
3. In the event that wayside wires branching off from the right-of-way conduct the signals elsewhere, nonrailroad persons would be unlikely to pick it up, since the frequency employed is much lower than that used for general radio reception and transmission. Should it be picked up by another railroad on the same frequency at a distance through crisscrossing wires, the use of frequency modulation makes it possible to communicate satisfactorily during such times, as only the loudest signal is heard if more than one signal is on at one time.

Transmitter. Voice currents delivered from the microphone circuit modulate the carrier frequency delivered by an oscillator. The modulation is a frequency modulation and is accomplished by means of a reactance tube that varies the frequency of the oscillator over a predetermined range at a rate which depends on the frequencies of the voice



Locomotive showing equipment box on running board The pipe shown is part of the transmitting loop (Courtesy Union Switch and Signal Co)

currents. The output of the modulator is amplified in two stages, the last consisting of four 6L6 tubes. The modulated carrier current goes to the output transformer, which supplies the energy to the transmitting loop.

Receiver. At the receiving station, the energy is picked up by receiving coils and is amplified in its received form in two stages of a carrier-current amplifier. It is then heterodyned with the output of an oscillator to produce an intermediate frequency, which, because of the relatively low frequencies used in inductive communication, is chosen preferably higher than the carrier frequency. The intermediate frequency which carries the initial modulation is then amplified through two stages. After this amplification, it goes through a discriminator—the frequency modulation term for a demodulator. Here the voice frequency is separated from the intermediate frequency. The voice frequency is then further amplified and delivered to the loudspeaker or telephone receiver. The band of frequencies used in this system is about 6000 cycles in width, that is, 3000 cycles on either side of the nominal carrier frequency. This makes available a voice band from approximately 200 to 2750 cycles, which is capable of giving a satisfactory reproduction of voice.

Power Supply. The power supply consists of a dynamotor which is energized from a battery in the case of a caboose or a diesel-electric engine, and from the headlight generator on a steam locomotive. Where voltages other than the usual type, such as 32 volts DC, exists—for example, 64, 78, or even higher voltage for diesel-electric locomotives—it is energized either by a voltage changer consisting of rotating machinery or a voltage reducer consisting of resistors. It is possible to provide dynamotors with the appropriate primary voltage, so that no additional apparatus may be required. The extreme power requirements of the two-frequency equipment is approximately 250 watts during standby or reception, and from 500 to 600 watts during transmission with likelihood of becoming less during the future.

Equipment Types. In addition to two-way single-frequency equipment, two-way two-frequency vehicle equipment is also utilized, as on the Pennsylvania Railroad. This is useful for break-in to converse independently in each direction. This involves one transmitter capable of transmitting on two frequencies by means of change-over relays. Such an equipment has two independent receivers, one for each frequency; one loudspeaker; one handset; and two receiver coils, one of which is tuned to each of the two frequencies. The transmitting loop is common to the two frequencies and is tuned to the desired frequency by additional contacts in the same apparatus which selects the transmitter frequency.

To send an emergency call, the signal lever is moved back and forth between its two extreme positions, sending a characteristic signal on each of the two frequencies. The signal on each frequency has a characteristic pitch, and it is easy to distinguish which frequency is being heard. Stations in range of only one of the frequencies will hear an intermittent signal, while those in range on both frequencies will hear the calling signal of both.

On the control panel, there is a manual volume control for the incoming signal. A red light shows when power is turned on. A side tone on the handset shows that modulation is going out over the transmitting loop. This side tone enables the speaker to hear himself by way of the transmitting loop and the corresponding receiver operating at a very much reduced gain. To keep the operator informed that his receiving amplifier is in sensitive operating condition, the squelch circuit is so adjusted as to produce a very small amount of hissing noise in the receiver.

Constructional Features. In the case of two-way two-frequency equipment there are four equipment frames; namely, power supply, transmitter, and two receivers, all arranged to make the necessary connections by simply pushing them into their proper positions on the shelf. A set

of plugs at the back of the frame meshes with corresponding sockets built on the shelf. The frames are clamped in position by means of levers that are visible on the front of each frame. The whole shelf is resiliently mounted at both ends to protect the equipment against shocks and the violent jolts occasionally encountered in railroad service. The shelf is cushioned front and back with sponge rubber. All frames are interchangeable with corresponding frames in other sets and are coded so that they will not fit in the wrong position in the equipment box. The box itself is of sturdy waterproof construction, as is necessary in locomotive applications. On a vehicle, the transmitter, receivers, and power supply are included in one equipment box.

The equipment box for locomotive or caboose containing all units weighs about 500 pounds for a dimension 18½ inches deep, 21 inches high, and 48 inches long, of which the steel equipment box permanently mounted weighs about 350 pounds. The individual detachable units within the equipment box weigh about 50 pounds each. The control box weighs 20 pounds, being about 8 inches square and 4 inches deep.

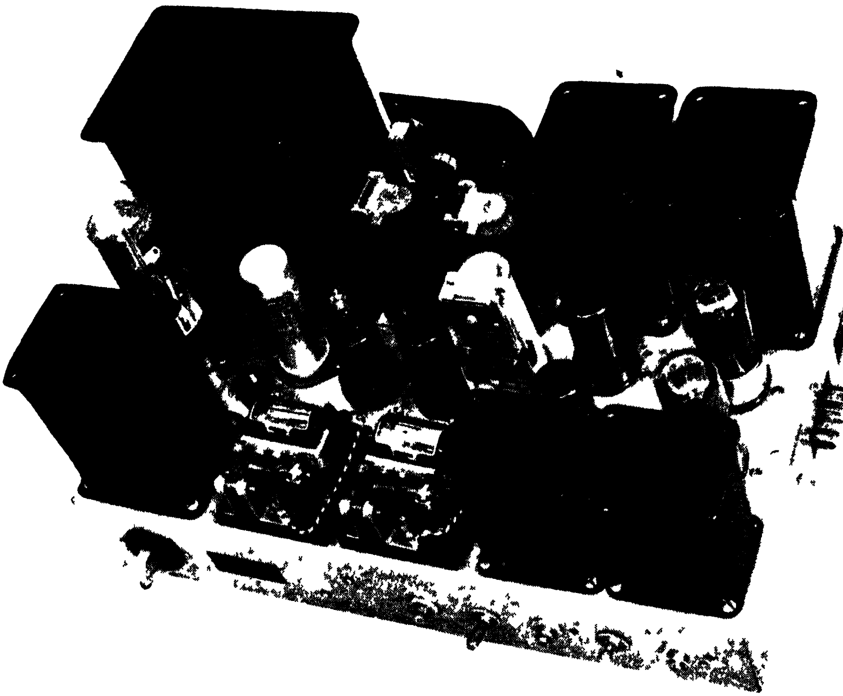
10 Halstead Induction Radio System

The Union inductive system just described requires rails, which, of course, would normally be available in railroad service. They are essential to the system so that the transmitter can conductively feed radio-frequency signal energy into them for transmission. Because of this, a limited amount of communication for nearly a train length is possible even if no wayside wires exist.

The more common type of induction communication—more correctly called induction radio—was described in Chapter Nine, since it has wide application in other fields than railroad alone. This is exemplified by the Halstead induction radio system, developed and manufactured by the Halstead Traffic Communications Corporation. This type of system can function normally without the railroad track, but requires that mobile units be within a lateral distance of about 100 feet and, if necessary, several hundred feet from normally existent wayside wires or a special transmission cable.

This system has reached such a high state of development that, even on frequencies as high as 3000 kilocycles and higher, walkie-talkie equipment utilizing a quarter of a watt power and weighing less than 5 pounds has been able to communicate 20 miles with another walkie-talkie equipment, so long as both were located underneath or close to usual wayside wires, such as 20 feet beneath them.

The induction radio system does not require any physical connection with wayside wires or with the rails, either at fixed or mobile points,



Two-channel receiving amplifier and automatic pulsing unit employed in installation of railroad radiotelephone equipment. (Courtesy Halstead Traffic Communications Corp.)

for normal communication. It therefore does not require that the trucks of railroad rolling stock be insulated from the body of the vehicle. At fixed stations, less power is required than at the mobile station for the same amount of signal or communicating range. For example, 10 watts there can match 25 to 50 or even more watts at the mobile station. This is because the fixed station can provide superior inductive coupling in much closer proximity to the wayside wires for both transmission and reception. This makes possible a greater transfer of signal energy between wayside wires and equipment, or vice versa. This type of apparatus has already been perfected for military operations, utilizing either amplitude modulation or frequency modulation. As in any other radio application, FM is usually preferred by most engineers, wherever and whenever sufficient channel space makes it possible. By using relatively low deviation ratios, FM is possible on all but the very lowest frequencies suitable for induction communication.

At the fixed station, signals fed into the microphone go into the transmitter. From the transmitter, the signals may go through a radio-frequency attenuator unit which regulates the amount of power allowed

to be impressed on the wayside wires. It then continues through a contact relay to an induction cable located in close proximity to wayside wires for a distance of a few hundred feet. The attenuator unit, when employed, is used to facilitate induction or increase in signal energy impressed on wayside wires. The signals impressed on the wires follow the conductors for the length of the signaling zone, for example, 75 to 100 miles. Any other fixed or mobile station picks up or transmits signals by inductive coupling to provide two-way communication.

The induction field surrounding the wayside wires is employed in bridging the relatively small gap between the wayside wires and a mobile unit proceeding on the railroad track running parallel to the wires. A loop on the mobile unit picks up the induction radio signal energy. By means of an associated receiver and loudspeaker on the mobile station, the signals are reproduced within the vehicle.

The mobile station is similar to the fixed station except that it depends on a loop instead of an induction cable as its antenna equivalent. Since the loop of the mobile station ordinarily is farther away laterally from the wayside wires than the coupling medium employed at the fixed station would have to be, and since it is also of a smaller size, the difference is compensated for by increased transmitter power at the mobile station.

On a mobile unit, the transmitter/receiver loop may range in size from a two-foot square or round to any feasible size for the vehicle in question. The larger the loop, the less transmitting power is required for a given impressed signal on wayside conductors. The larger the cross section of the wire used in the loop, the lower will be its resistance per unit length, and the greater its resultant efficiency. The smallest loops may require as much as 25 turns, while the larger one may need only about 5 turns of wire. Multistrand wire of as heavy a gauge as may be feasible is ordinarily utilized in the construction of the loop.

The loop is mounted in such manner that its plane is parallel to the vertical plane passing through the wayside wires, that is, parallel to the wayside wires. The design and placement in every case should be such as to permit the maximum induction transfer between the vehicle and the wayside wires. The same loop can be used both to transmit and receive in a simplex system.

For a mobile station to transmit to a fixed station or other mobile units, signals from the microphone pass through the transmitter into the loop. This causes intense induction and radiation fields to surround the loop, which induces a signal voltage on the wayside wires. The signals then follow the wayside conductors along their length to the central station where, as a result of the close proximity of the FM induction cable to the wire circuit, sufficient signal pickup is obtained. From the

cable, it passes through the fixed station transfer relay to the receiver and thence to the loudspeaker.

For one mobile station to transmit to another mobile station, the signals are impressed into the wayside wires in the same manner. At the other mobile point or points, the gap between the wayside wires and the mobile loop pickup device located on the locomotive or caboose on the track is bridged inductively and independent of any physical connection. Once picked up on that loop, the signal is handled in a similar manner to that of the fixed station.

Two-way communication thereby becomes possible for five different legs of communication:

1. Fixed station to mobile station.
2. Mobile station to fixed station.
3. Mobile station to mobile station.
4. Fixed station to fixed station.
5. Front to rear of same train, or vice versa.

Suitable equipment is also developed and tested which makes possible walkie-talkic applications in connection with facilities of this type.

In the event that the signaling distances are not sufficient to cover the railroad applications involved—for example, farther than 50 to 100 miles—automatic repeater equipment may be provided in the Halstead system for use at strategic wayside points. A local microphone and loudspeaker are incorporated in the repeater equipment to facilitate the use of the equipment for local zone communication as well as to perform the functions of a repeater or booster station. Signals from the central station or mobile units are picked up by a receiving antenna (that is, induction cable or loop) extending parallel to the wayside wires, usually for a few hundred feet. Signal energy picked up from the wayside wires is delivered to the repeater station receiver. A carrier-operated relay in the receiver is actuated by an incoming carrier signal which then turns on the zone transmitter. Signals from this zone or repeater receiver are then impressed on the input circuit of the zone-repeater transmitter, which retransmits and reimpresses the signal on the wayside wires again. It does this on a different frequency, sufficiently removed from the incoming frequency so they do not interact or interfere with each other. Because two frequencies are then involved, the mobile station employs either a dual-frequency receiver or utilizes push-button tuning for any number of zone-frequency channels required.

Induction forms of communication, in some respects, are less efficient than space radiation forms of communication, since the latter employ antenna systems that can be matched properly for maximum propagation

into space. The former, on the other hand, utilize existing wayside wires that have not been specifically or ideally designed for the application. However, it is not necessary to have a very high percentage of efficiency to realize two-way communication for useful and substantial distances. The receiver at either a space radio or an induction radio station is sensitive enough to function with a few microvolts or even less input, particularly if the frequency is of a higher order. To provide these few microvolts inside the receiver at a distant receiving point, the induction radio transmitter may impress several volts into the wayside wires at the transmitting point. This can be accomplished with 10 watts at the fixed station and with 25 to 50 watts at a mobile station on a railroad or highway.

The radiation field falls off as the inverse square of the distance. The induction field varies with the inverse cube of the distance. This more rapid attenuation in space reduces the range possible for train-to-train communication as compared to train with fixed point, since in the latter case there is only one gap to bridge instead of two. The attenuation in bridging the gap is greater than many miles of travel over existing wayside wires to a fixed point. This is less important when the wires on the wayside are reasonably close to the mobile vehicle.

The signal-strength limitation is the requirement of the Federal Communications Commission that the field signal strength be not more than 15 microvolts per meter at a distance in feet from the transmitting point equal to 157,000 divided by the frequency in kilocycles which may be employed. At 10 kilocycles, the signal must not exceed 15 microvolts per meter at a distance of 15,700 feet from the transmitting loop. Since wayside wires are usually less than 100 feet from the locomotive or caboose, this means that it is possible to generate a very strong field at the distance of the wayside wires, and therefore they will have a correspondingly strong signal impressed on them. At 100 kilocycles, the frequency being 10 times greater, a distance of 1570 feet is involved before the signal must drop to 15 microvolts per meter. Therefore the initial signal must be stronger than when 10 kilocycles is employed. However, the signal intensity within several hundred feet of wayside wires will still be relatively great, particularly when very efficient receiving equipment employing frequency modulation principles is used. Also, at 100 kilocycles, less noise in proportion to signal will exist than at 10 kilocycles. FM is feasible to utilize at 100 kilocycles, whereas at 10 kilocycles the over-all frequency spectrum is too limited to permit the use of FM with any satisfactory deviation ratio. The lower noise level and the use of FM therefore should so favorably affect the signal-to-noise ratio at the receiving point that it will make up for the weaker impressed

signal on the wayside wires at the transmitting point when the higher frequency is employed.

In general, for any type of induction radio communication, a frequency should be used at which the distance given by the FCC formula for 15 microvolts per meter field intensity exceeds by many times the distance between the loop on the mobile vehicle and the placement of the wayside wires at their closest point. Then there is a sufficiently high field strength by the time the gap is spanned between the mobile vehicle and the wayside wires, without exceeding the field intensity of 15 microvolts per meter at a distance in feet of 157,000 divided by the frequency in kilocycles.

Because of the present FCC formula, induction radio communication in conformity with existing regulations of the FCC is not feasible on high, very high, ultra high, or super high frequencies. However, development work continues, and the Halstead Traffic Communications Corporation has already found it possible to operate on frequencies higher than 3000 kilocycles. In fact, Halstead highway radio systems have been tested on the standard broadcast band between 550 and 1600 kilocycles. Such utilization has in the past made it possible for this company to provide systems which enable motorists to use their standard automobile broadcast receivers without requiring special equipment, installation, or expense of any kind in order to receive in their cars special communications originating from fixed control points. Where facilities are desired to answer back, it is necessary only to procure transmitting facilities without purchasing or installing specific receiving equipment.

The longitudinal transmission range possible along wayside wires with induction radio depends on the following:

1. Degree of continuity or discontinuity of wayside wires.
2. Size, number, metallic composition, resistance, placement, and insulation of wayside wires.
3. Strength of the signal at the transmitting point.
4. Size and placement of the induction loop or induction cable at the transmitting and receiving points.
5. Gap to be bridged at a lateral distance between the loop or cable at transmitting and receiving points and at various wayside points.
6. Prevailing noise levels in the vicinity of the wayside wires that may be introduced into the receiver as background noise and thereby influence the signal-to-noise ratio.
7. Whether frequency modulation or amplitude modulation is employed. Also, if FM is used, whether enough frequency swing or deviation ratio is utilized, so that it will differ sufficiently from the frequency characteristics of undesired noises that are adverse to favorable signal-to-noise ratios.
8. Sensitivity of the receiver.

While much greater communication ranges would be possible with a special wayside cable designed for the purpose, particularly if located

between two sets of tracks at a level closest to the loop heights, existing wayside wires are usually satisfactory. For example, high-tension power lines usually employ copper wire of low resistance and large cross section with excellent stand-off insulation. Such lines also have rather good continuity. This provides a much better path than a greater number of small steel telephone or telegraph wires mounted on simple glass insulators, which may be more susceptible to moisture and soot.

Once a signal is impressed on wayside wires, if some of the wires terminate, then the remaining wires continue to carry the signal onward. They not only carry the signal onward, but also reimpress or reinduce some signal back into new wires that run along from there or subsequent points. Each wire guides an induction field as well as the combined field developed by the combination of wires. The field that they guide may be complex if one were to isolate the effect of each wire and the part it plays in making up the total, but in any case it is sufficient to provide lengthy and useful communicating ranges for railroad and similar applications. If every wire should terminate at the same place, and a great gap of distance prevail without wires of any kind, then induction radio communication would become impossible in such areas where the wires are absent for an extended distance, except possibly for a few hundred feet from direct induction between the two pickup loops. Power companies have been able to communicate with their field trucks about a quarter mile away from their power lines by using induction radio principles. It is said that this can be done for as much as a mile, but that admittedly sounds too optimistic. So long as wires exist, or even if they are interrupted, but not all at the same spot, there will be sufficient overlap so that communication will continue to be possible for any distance as long as the signal is stronger than the background noise. The more interruption encountered by the wayside wires, the more signal attenuation or diminution takes place with distance, and the less useful communication range is possible.

Constant Check of Equipment Performance. In the case of railroad mobile applications, equipment must function properly at all times. In lieu of that, it must be immediately evident to the locomotive engineer that the equipment is not operating satisfactorily and cannot be depended on for receipt of dispatching instructions if complete reliance is to be placed on the two-way radio facilities.

The Halstead Traffic Communications Corporation has developed an automatic checking unit that goes into operation during periods of no actual message communication. During that time, it flashes an indicating light on the mobile equipment at sufficiently frequent intervals and provides a tone signal in the cab. Pulses are transmitted usually at

intervals of three to five seconds, such pulses being of momentary duration and definitely distinguishable from other sounds heard in locomotive cabs. This unit incorporates a motor-driven switch or an electronic interval timing switch to key the transmitter at regular intervals for a fraction of a second each time. The tone signal or checking signal impressed on the transmitter is usually of 300 cycles or lower frequency.

To prevent interference between the automatic checking signals and incoming communication signals from mobile or secondary stations, a carrier-operated relay in the central station receiver, called the pulse lockout relay, automatically locks out the pulsing operation as long as an incoming carrier signal is present. The same relay serves also to operate a carrier pilot light which is useful as a visual calling signal to indicate that the channel is being used. This same type of automatic pulsing unit can be used with any kind of space radio or induction radio system and is not confined to induction forms of communication alone.

The locomotive engineer is thus reassured every five seconds that his equipment is in good operating order to hear the dispatching point. If he fails to notice any light or tone for a period exceeding five seconds, he knows that either the fixed station or his own receiving equipment is inoperative. He can then follow precautionary procedure, checking up or making the necessary parties aware at the earliest opportunity that the equipment is inoperative.

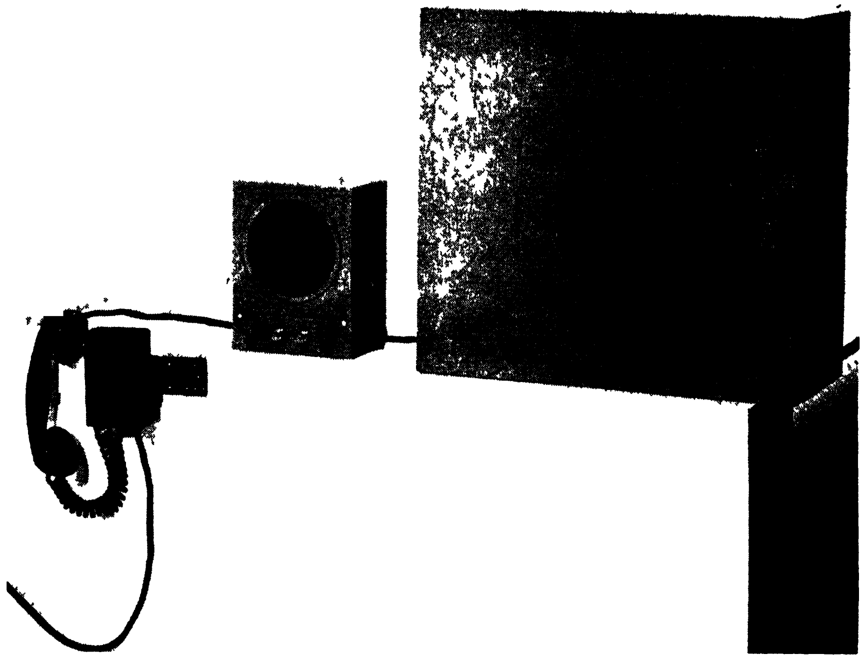
The type of carrier check equipment is not peculiar to induction radio alone and may be used with space radio equipment facilities also. The manufacturer also has developed alternate or supplementary very-high-frequency or microwave space radio equipment to use in a complete communication system.

11 Aireon Induction System

The Aireon Manufacturing Corporation (formerly known as the Aircraft Accessories Corporation) has successfully completed an induction radio system on the Kansas City Southern Railroad that has attracted much interest and attention in railroad circles and is being adopted elsewhere.

The wayside station couples to wayside wires in a manner comparable to the Union induction system, while the mobile station is inductively coupled in a manner comparable to the Halstead system. Noteworthy features are frequency modulation, automatic squelch, transmitter adjustable attenuating device, compactness, and costs in line with what a system must be in order to assure wide adoption.

There is a great disparity between the fixed and mobile station with respect to power and equipment cost. Because the wayside station



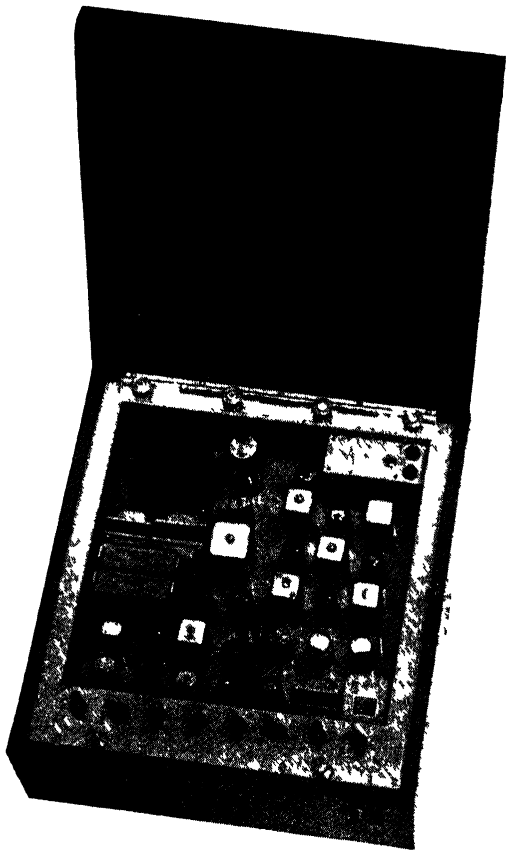
Three-unit FM wayside station set (1) Push-to-talk combined telephonic handset to talk and listen, (2) remote control speaker dials to regulate noise and volume, lights indicate listening or talking, (3) transmitter mechanism for either wall or standing-position mounting (Courtesy Aircon Manufacturing Corp)

couples directly to the wires, the energy transfer loss is much smaller, so that 5 watts maximum power is sufficient The mobile station must use 10 times that power or even more to duplicate that performance. Where it is not feasible to couple directly to the wires and induction methods must be utilized similar to the Halstead system, then more power at the wayside station is required. In some cases, direct coupling may not be desirable because of circuit problems that may develop from the primary use of the wires

Wayside Station The office unit is contained either in a standard rack or a cabinet which may be wall mounted or desk mounted If mounted in a rack, all controls and tubes are on the front panel with adequate designations and graduated scales, so that instructions for adjustments may be given by telephone to nontechnical personnel. A dust cover may be removed easily for access to wiring and small parts. All cable wires are numbered for ease in tracing The entire unit may be removed by removing one plug and eight screws When mounted in a cabinet, the opening of a hinged front door allows access to all controls and tubes. If access behind the tube sockets and other wiring is desired, two thumb-

screws allow swinging out for complete inspection Outside dimensions of the main unit are 19 by 20½ by 9 inches.

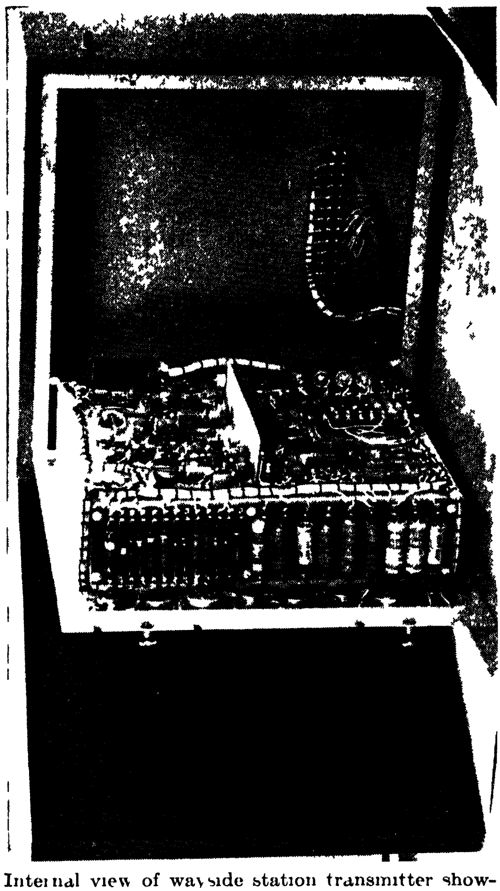
The basic circuit comprises a frequency modulation transmitter and receiver combination designed to operate in the low-frequency portion of the spectrum (approximately 70 to 200 kilocycles). The transmitter



Internal view of FM wayside station transmitter, emphasizing hinge construction on left for ease of swinging entire internal mechanism for servicing or replacement Two thumbscrews at right release fixed position Entire internal structure then swings to left on hinge (Courtesy Aireon Manufacturing Corp)

section comprises a stabilized oscillator, an audio amplifier and reactance tube, and a Class C power amplifier, whose output power may be coupled between one of the wayside wires and ground, or between two wayside wires and ground in simplex fashion through appropriate tuned filters The power output of the transmitter as delivered to an average simplex

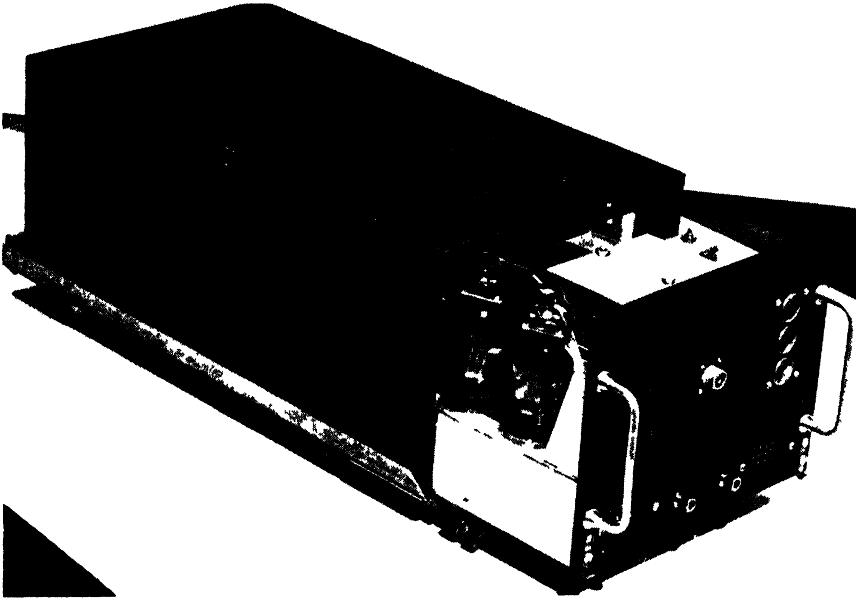
line circuit is adjustable in six steps from approximately .1 to 5.0 watts. This adjustable feature provides a means of setting the power output to conform to a particular local circuit requirement The FM receiver contains two pretuned radio-frequency amplifiers, a limiter and discriminator



Internal view of wayside station transmitter showing wiring and ease of accessibility for servicing and replacement Provision is made on cable terminals on inside of back cover for future connection to A T &T. or other passenger-telephone communication system (Courtesy Aireon Manufacturing Corp)

circuit, and an audio amplifier, whose audio output is adjustable by means of volume control on the operating panel.

To minimize interference from noise, special circuits have been incorporated to provide automatic noise-squelch action without manual adjustment, except for service control for initial adjustment upon instal-



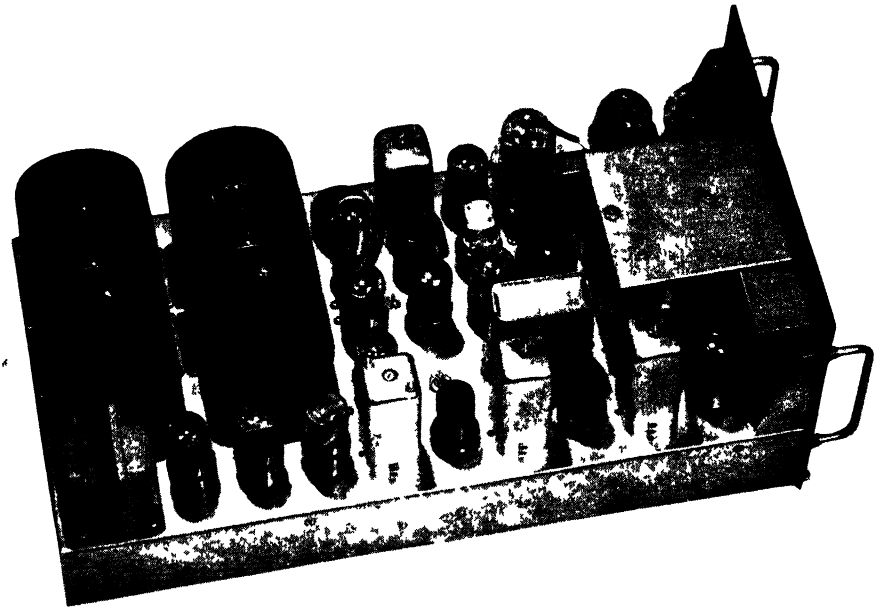
FM mobile unit transmitter for engine cab, caboose, or emergency, showing drawer-slide arrangement within dust cover. Dust cover is mounted on specially designed rubber shock mounts. (Courtesy Aireon Manufacturing Corp.)

lation. The design of this squelch circuit is such as to provide practically complete noise-free reception for all anticipated values of received signal-to-noise ratio. Either the transmitter or the receiver is in operation at one time but not both. However, no common operating components or tubes are employed in the transmitter or receiver.

To facilitate remote control operation of the equipment (for example, control over a considerable distance by means of a dispatcher's telephone circuit), an automatic voice-operated device is provided. This requires that the receiver and transmitter be interlocked electronically to permit operation on a talk-to-talk basis. In conjunction with this facility, no relays or mechanical switching devices are employed; in fact, all switching is done electronically.

In the event that automatic operation is not required for a particular local control installation, means are provided for operation on a push-to-talk basis by a slight modification of terminal connections. These features are incorporated in all station equipments, because the manufacturer's engineers feel that many railroad operating conditions will require remote control of distant or unattended stations.

Mobile Station. The mobile unit, used in either engine or caboose, is contained on a shock-mounted ATR type of rack. The dimensions are



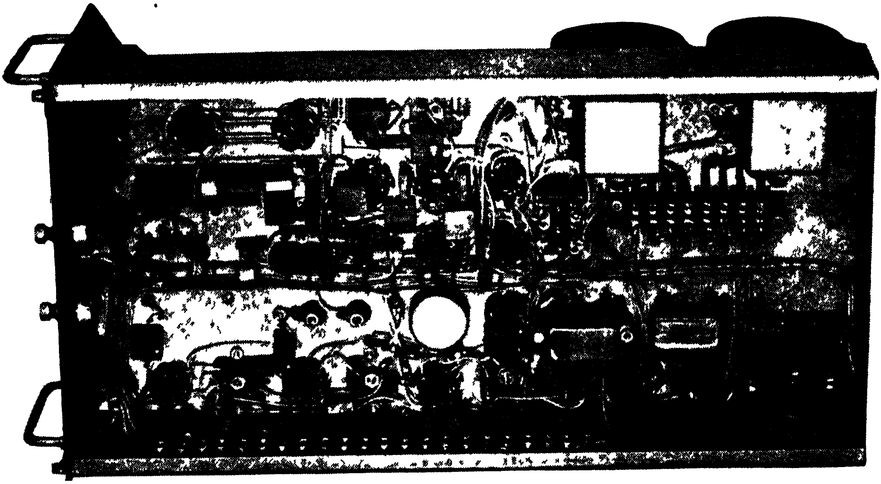
Internal top view of FM mobile unit transmitter for engine cab, caboose, or emergency use. This unit slides into dust-cover box and can be immediately replaced (Courtesy Aireon Manufacturing Co.)

20 by 8 by 10 inches, and it weighs about 40 pounds. It can be removed by removing three plugs (which cannot be connected incorrectly) and two thumb nuts. All necessary adjustments may be made from the front panel with a screw driver. The dynamotors have sealed bearings, hence no lubrication is necessary. The remote control box contains the handset hook and the two controls—initial noise-limiter adjustment and volume control—which normally need no adjustments. The cover is easily removable for inspection.

The power supply is designed for operation from a 24-volt DC source, but special equipment can be supplied on order for use on other DC battery voltages or with 115-volt 60-cycle alternating current.

The power input requirements are 400 watts (approximately 16 amperes current drain at 24 volts) for periods of transmission, and 100 watts (approximately 4 amperes current drain at 24 volts) standby power for continuous operation of the receiver.

The basic circuit includes a combination frequency modulation transmitter and receiver both pretuned for use between approximately 70 to 200 kilocycles. The receiver section contains two radio-frequency amplifiers, a limiter and discriminator stage, a noise-squelch circuit similar to that employed in the wayside station equipment, and an audio



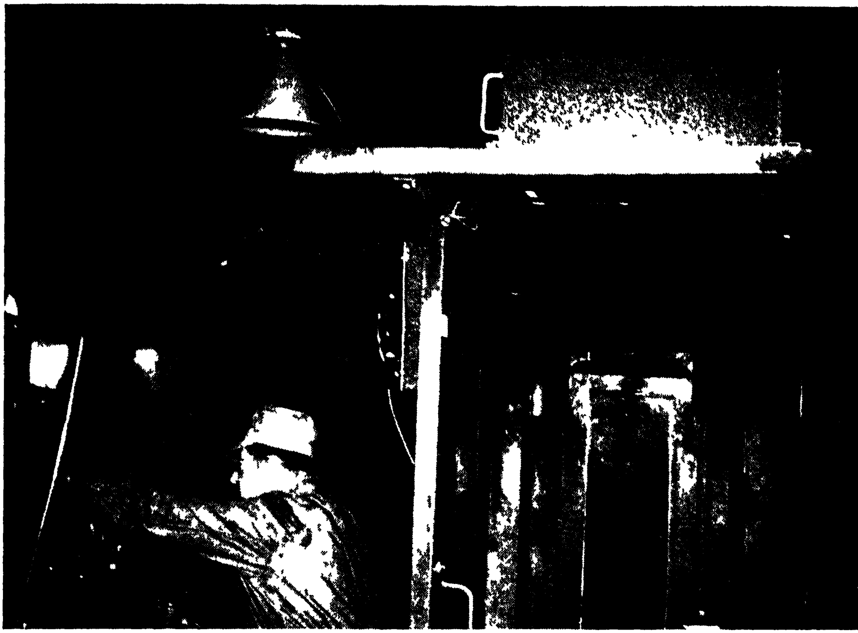
Internal bottom view of FM mobile unit transmitter for engine cab, caboose, or emergency, showing wire arrangement (Courtesy Aireon Manufacturing Corp.)

amplifier capable of delivering 6 watts of undistorted audio power. This amount of output is considerable and is ample for all mobile requirements.

The transmitter section employs a stabilized oscillator, an audio amplifier and reactance tube, and a Class C amplifier output stage which feeds 50 watts of carrier power to the loop antenna. The mobile equipment operates on a push-to-talk basis. While the handset is hanging on the hook switch, all calls for the particular caboose or locomotive in question are received on the loudspeaker. When the particular mobile unit is called or desires to communicate with other radio equipment on the line, the trainman removes the handset from the hook and operates the equipment as though it were a conventional telephone circuit, except that it is necessary to push the handset button before talking and to release it during listening periods. In a typical caboose installation, the equipment would be installed in a cabinet, so that it can be locked and made inaccessible. The storage battery can be mounted on a metal box placed under a seat in the caboose or in a cabinet.

For locomotive installations, the equipment is mounted either in the cab of the locomotive or in a weatherproof box on the deck of the tender, depending on the type of installation desired, as influenced by the type of locomotive under consideration. If the equipment is mounted on the tender, it can easily be remotely controlled from the cab without extra equipment.

The remote control unit, on which is mounted the hook switch for holding the hand telephone set, the audio volume control, and signal-indicating lights, is designed for mounting either in the locomotive or



Typical installation on steam locomotive of the Kansas City Southern Railroad. Above engineer's head is suspended the loudspeaker. On rack above doorway is the transmitter-receiver unit. Microphone-earphone combination is mounted behind and above the engineer. (Courtesy Aireon Manufacturing Corp.)

in the caboose. For caboose installations, the control unit should be mounted on the wall most accessible to the train crew. The loudspeaker unit is provided with a universal-type mounting bracket and should be so located in the caboose as to give the best distribution of sound. Experience indicates that the best position is usually at the end of the caboose.

In the event that a combination carrier current and space radio system is employed on trains, it will be necessary to have available a control unit capable of operating either type of communication equipment from a given point in the caboose or locomotive. A remote control unit is designed to provide this dual function, in which a typical installation could involve space radio for end-to-end communication and carrier current transmission for wayside-to-caboose and wayside point-to-point services.

An approximate estimate of costs for current equipment models thus far is about $500 for the wayside station and $1500 to $1800 for a mobile installation complete with battery and generator for caboose or locomotive. No modification of the rolling stock or bonding of rails is necessary in its operation.

Performance Data. On the basis of the following data, the manufacturer has been successful in wayside-to-caboose and head-to-rear transmission for wire spacing up to 300 feet from the track, and for wayside wire position vertically from 100 feet below to 100 feet above the track level. Wayside-to-train communication can be carried on, except in the worst summer electrical storms, for at least 75 miles. Summer static reduces this figure to 50 miles.

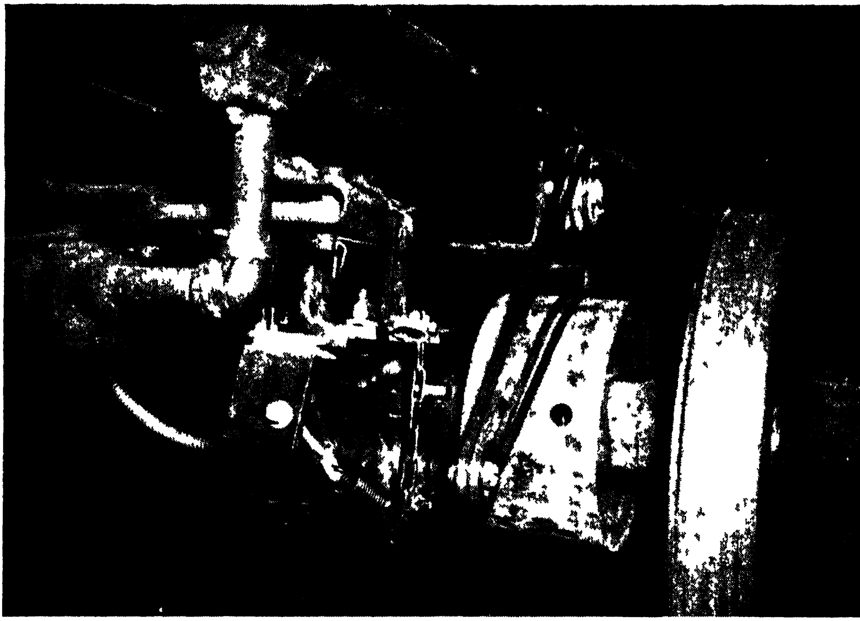
1. The average attenuation in signal strength between the loop antenna on the caboose and wayside wires, for closest possible spacing between the track and said wires, is about 25 decibels at 170 kilocycles.
2. This attenuation figure is 30 decibels for head-end installations because of the lower Q obtainable with engine loops as a result of the large amount of metal in the field.
3. As the distance between the track and wayside wires increases, the attenuation increases at the rate of 1 decibel per 10 feet of additional spacing.
4. The attenuation along the line is about .6 to .75 decibel per mile at 170 kilocycles. Wet weather operation will increase this to about 1 decibel per mile.

The decibel expresses the ratio of power output to the power input. In the case of sound, it is approximately the smallest change in the intensity that the human ear can detect. Each reduction of 3 decibels is equivalent to halving the power. Each increase of 3 decibels is equivalent to doubling the power. For the performance data indicated, the power losses are as follows:

1 decibel loss means only .7943 of the power remains.
25 decibels loss means only $1/316$ of the power remains.
30 decibels loss means only $1/1000$ of the power remains.

This means that the minimum loss possible between rolling stock on the track and the wayside wires is equivalent to the loss that would exist along 25 miles of travel on the wire itself, once impressed there. While only $1/1000$ of the power can be transferred from rolling stock to the wire, only 1/100,000 of the power at the transmitting point at one end of the train can reach the receiving point at the other end of the train, because the over-all loss may be 60 decibels instead of 30 decibels aside from loss in the wire itself. That is why low-powered microwave or very-high-frequency space radio for front to rear is recommended, unless the signal can be relayed back to the rear from a fixed station.

The Aireon Manufacturing Corporation believes that over half of the railroads in the United States can use such an induction system for their operations, except for large terminals and yards where a considerable number of small industrial sidings may make the installation of specially constructed overhead wires too expensive. Furthermore, in such large yards, as in Chicago, the number of roads using these facilities is such



Charging generator installed on caboose to operate two-way radio equipment (Courtesy Aireon Manufacturing Corp)

that frequency discrimination would be more practical on a space radio basis The company therefore, in its approach to the problem, does not specifically differentiate between carrier current and space radio Instead, it prefers to use the approach that an integrated system is required for each railroad and that each railroad presents a separate problem. Thus, some railroads might require 90 per cent induction and 10 per cent space radio, or vice versa, depending on the nature of the terrain, number of large yards, wayside wire prostration due to sleet storms, or the like.

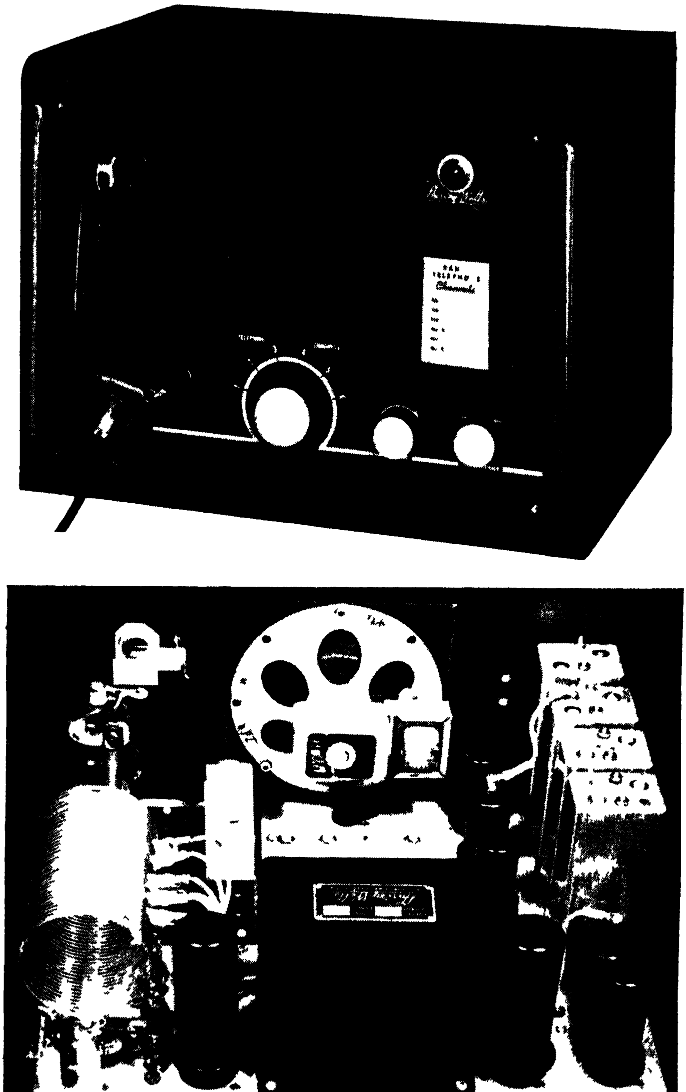
12 Medium-frequency Space Radio Communication

This band of frequencies has some usefulness in railroad communications for marine activities, which at sea, on the Great Lakes, and in rivers or harbors may be of great scope. Such equipment is also very feasible for emergency or auxiliary communication use between fixed points during periods of wire prostration or abnormal traffic load. It is flexible enough to be used in an integrated system to tie in with other agencies and even to be used on railroad vehicles, in town-to-train, train-to-train, and other routine railway services.

Such equipment operating as it may in a frequency band, such as 2000 to 3000 kilocycles or even higher, utilizes radiated signals having both

ground-wave and sky-wave components, useful for distances that arise in railroad service. It is a compromise between sky-wave communication on low frequencies and ground-wave communication on very high frequencies. At these frequencies, low or moderate power can provide useful ranges that would not be possible on lower frequencies. The ground-wave coverage will be comparable with very high frequencies or better, particularly if backed by sufficient power. While not so bad as short waves or high frequencies, there would be a tendency at night to have a skip distance effective over several hundreds of miles. During the day, fairly consistent coverage may be realized for 50 or more miles, depending on antenna height, location, and transmitter power rating. The sky wave will reflect back to earth near by enough to carry on where the useful ground wave terminates, thereby extending the consistent signal distance. At night, the ground wave will function at distances of 25 to 50 miles, but the sky wave may return to the earth at distances of 500 miles or more. Between this 50 and 500 miles, signals will either fade or skip and be erratic in behavior with likelihood of being unusable for most of that skip area. The sky wave will return to the earth at closer distances for useful communication if the lower-frequency end of this band of frequencies is used instead of the higher-frequency end. For example, the sky wave may return for 300 miles at 2000 kilocycles at night, while not returning for 500 miles at 3000 kilocycles, and perhaps 800 miles at 4000 kilocycles. The distance will be less in summer and more in winter. It will be least in daylight and maximum at night. During winter when the nights are longest, the skip will be greatest. In parts of the world extending each side of the equator, or zones of daylight and darkness as between extreme changes in longitude, this becomes confused, and fading will be experienced where the signal is subject to the effects of day and night simultaneously. The transmitting point controls this. The signal may leave there in darkness but not be reflected until it gets to a twilight or daylight zone, or vice versa. The height of the ionized layers will determine the skip distance. This, in turn, will depend on whether the layers are high as during darkness or low as during daylight. When the reflecting layers are low, the signal will return to earth sooner. When they are higher above the earth, the sky-wave component will return to earth farther away.

Medium-frequency equipment is already available in a wide range of types, power, channels, and prices. It is also in regular production for a choice of power supplies, such as 6-, 12-, or 32-volt battery operation or 110 volts AC or DC. Dynamotors, converters, and vibrator power supplies are available to operate from any available source. Some types are available whereby the same equipment can function on a choice of power



Harvey-Wells Model MR-25 six-band crystal-controlled radiotelephone. Two receiving and two transmitting crystals are visible on chassis. The other eight crystals are not in this illustration. (Courtesy Harvey Wells Communication, Inc.)

supplies merely by changing the plug from one power socket to another on the chassis. Usually when that is the case, one socket is for 110-volt 60-cycle single-phase alternating current to operate from commercial lighting circuits, while the other is either 6, 12, or 32 volts DC for storage

battery operation. Operation is then possible either from batteries or 110 volts AC. At the same time, charging of batteries may be done while the vehicle is at a terminal or in port, at which time communication can be maintained from an AC circuit. Also, the battery may be charged or floated by a charging generator while the vehicle is in motion.

These equipments are available in price ranges between $200 and $1000 or more, any of which can render effective communication. Regular production models are available in up to 10 channels of reception and of transmission, every one of which are preset, crystal-controlled, and fool-proof provided each channel is licensed by the FCC. On special order, they can be provided with an unlimited number of additional channels. Automatic call ringing systems are also available on special order.

To illustrate the application, the Harvey-Wells MR-25 is described here. This equipment is ordinarily intended for ship-to-shore, shore-to-ship, and ship-to-ship communications by radiotelephone on the marine frequencies between 2000 and 3000 kilocycles on storage battery or regular lighting circuit. Several comparable equipments by other manufacturers are described elsewhere in this book. This particular model has 6 transmitting and 6 receiving channels, all of which are preset and crystal-controlled, so that no further tuning is necessary. Twelve quartz crystals are used. One transmitting frequency and one receiving frequency are paired for each channel of communication. The transmitting frequency may be either the same or a different frequency as compared to the receiving frequency, as the user may require. For example, Band 1 might be using 2110 kilocycles for transmission and 2506 kilocycles for reception, yet they are connected in their sockets, so that whenever the band switch is in position 1, they will automatically operate that way. This permits automatic channel changing merely by rotating the frequency switch to the various band positions. The time required to shift from one band to another is only momentary. Unskilled personnel can master the operating details after only a few minutes' instruction.

For railroad use, the 6 channels might, for example, be set up as follows:

Band 1. Towers and dispatching points.
Band 2. Railroad stations and administrative points.
Band 3. Humpyards and terminals.
Band 4. Front-to-rear or intertrain communication.
Band 5. Wayside communications (wayside personnel, motorcars, and repair crews).
Band 6. Repair shops, maintenance supervisors, and the like.
Additional bands for marine services, such as ferries, tugs, docks.

Each of these fixed or mobile points can have a clear channel as well

as be able to switch to any other group on occasion. An example of its flexibility is illustrated here:

1. A station master wants to talk to the conductor of a train. He moves the frequency band switch from Band 2, where he normally stands by, to Band 4 and establishes two-way contact with the train. When communication is completed, he shifts back to Band 2, where railroad stations belong, so anyone else can call him.

2. The engineer of a train needs to communicate with the repair shop. He shifts from Band 4, standby frequency for trains, to Band 6 and establishes communication. Upon completion, he may wish to get word back to the caboose, so he shifts back to Band 4. Then he may wish to communicate with a wayside crew, so he shifts to Band 5, and so on. When communication is completed, he stands by on his own band.

This type of equipment at present is designed only for amplitude modulation for frequency conservation. It is subject to the usual static as well as induction and other forms of interference peculiar to frequencies at which appreciable sky-wave reflection occurs. Considerable if not complete communication is available in any case. It might be very feasible for railroad applications where sky-wave interference would not be serious and adequate clear channel space is available, in areas like Alaska or in other less populated and less congested areas of the world. It is definitely useful for local applications on low power, except where channel space is unavailable because of other occupancy.

Because of its low power rating, medium-frequency equipment of this type may be energized readily from an independent or emergency power source. In the simplest isolated application, this may be no more than a \$25 wind generator, charging a \$10 storage battery and working automatically, ready for any emergency when other communication does not exist. In the event that all wires are down during a storm, any automobile battery can be used to operate the equipment for several hours. During the New England hurricane, this was actually done with similar equipment for thirty-six hours, with little letup of communication. The battery was replaced three times. Any automobile could have recharged the battery, if necessary, from its charging generator.

If the equipment cannot cover or reach the required point or points along the railroad directly, because of limited power or sky-wave skip distance, intermediate points along the railroad can be used as relays, either manually or automatically. This particular equipment requires the following power inputs for the types of power source that are available in railroad service.

6 volts DC—16 amperes to receive and to keep the transmitter tubes warmed up ready to transmit at any instant. If the transmitter portion is turned off during

standby, it can be reduced several amperes. During actual transmission on voice, it draws 28 amperes.

32 volts DC—3 amperes during reception and standby; 4 amperes during transmission on voice.

110 volts—About 1 ampere for either reception or transmission.

Simpler 10-watt equipment draws less than half this load. The 25-watt equipment may be operated at less than normal or maximum power with a reduction in current drain. For purely local applications, minimum power may be used, such as 5 watts.

The use of narrow-band frequency modulation techniques on medium frequencies in the future may make this type of equipment feasible for one component in a communication package comprising dual facilities. Such a type of planning has been undertaken for a projected bus-line system requiring exceptionally large coverage.

13 Very-high-frequency Space Radio Communication

Railroads that have radio or electronic engineers have been inclined to use police radio equipment already on the market in order to obtain immediate practical results with a minimum of delay in investigation of planning. Such equipment might be the standard 25 to 50 watts FM facilities operating in the 30 to 40 megacycle band, which can be purchased from various manufacturers at moderate prices, such as $500 to $600 or even less on contract, except where special power supply or additional features are provided.

This makes possible the immediate use of radio facilities for short-range services, such as front-to-rear communication for frieght trains and humpyard or terminal communications. Since such equipment has been in existence for more than ten years using amplitude modulation and more than five years using frequency modulation, little or no guesswork is involved as to its performance. In some cases, equipment designed for use on the 116–120 megacycle or 156–162 megacycle band is employed with similar results, except for its tendency towards microwave behavior. The spectrum width and the number of stations already on the VHF band make questionable whether the railroads can expect to be permanently located in this band in more than a limited way. The final answer seems to be in the use of much higher frequencies not yet extensively occupied by other services.

On the VHF band, operations are conducted on the basis of ground-wave communication ranges. There is no dependence whatever on sky-wave reflections or skip-distance communication, which may occur during very short periods at unpredictable times and for unpredictable periods or distances. When such sky-wave reflections do occur, they sometimes

result in brief intervals of reception or transmission over distances which may be anything from a few thousand miles to the opposite side of the world. The reason that more of this phenomenon has not been noted up to now is because the skip distance in many cases has corresponded to an oceanic location where no VHF radio facilities exist to receive, transmit, or interfere. It can conceivably be so great as to encompass the globe several times, since the skips and reflections between the earth and reflecting regions above the earth result in reflection which may produce such a phenomenon.

Such behavior is not desired and can cause some annoyance and confusion if each transmission is not adequately identified. (Police cars in New England pick up Pacific Coast communities, or vice versa. The Cape Cod system has been heard for surprisingly consistent periods with daily regularity by the Mission Ranch in Phoenix, Arizona, 2000 miles away, from 10-watt radio-equipped cars operated on 39,900 kilocycles. Alabama and Michigan state police cars on 37,500 kilocycles, using 50-watt FM equipment, actually interfere with each other at irregular intervals.) In addition, there are times when greatly extended local ranges, up to 200 miles or more, occur for brief periods due to low ionized patches aloft or an unusual conducting path, such as a foggy or misty atmosphere. (For example, the Maine State Police and the Cape Cod county system, at no point closer than 200 miles can pick up and even work each other as much as 5 per cent of the time on 39,900 kilocycles even with 10-watt mobile units.)

The skip range is less pronounced on the high-frequency end of the VHF band and is most pronounced on the low-frequency end of the 30-40 megacycle band. In fact, the 30-megacycle end may be expected to have one or more hours daily where skip distances and long-range communication will take place that will be 3000 to 10,000 miles in range. It is a function of the frequency or wave length and can occur regardless of the amount of power employed. On the 120 or 160 megacycle bands, this skip phenomenon is much less evident. Higher in the frequency spectrum it becomes even more rare or is undetectable.

A common mistake is to consider very high or microwave frequencies as being limited purely within horizon range and completely dependent on an unobstructed optical line of sight between the transmitting and receiving points. Horizon-range limitation is rarely experienced with properly operating FM equipment, except for the most unusual and extremely localized situation. Most FM two-way VHF systems in existence are operating several optical horizons of distance in regular service. Two to three horizons of distance is a normal condition in open country, being somewhat less in car-to-car applications.

Railroad trackage or wayside wires minimize the likelihood of deficiency in range. Railroads with their track rails of endless length, even where not specially bonded, are invaluable for providing beyond-horizon communication and for reaching beyond and around obstructions to the line of sight.

The behavior of very high and microwave frequencies is similar so far as ground-wave communication ranges are concerned. However, the very high frequencies below 300 megacycles have greater ability to work through dense foliage and around moderate hills or other obstructions, particularly as the 30-megacycle end of the band is approached. Although VHF wave lengths are considered to be very short in comparison with conventional frequencies, they still are not less than about 30 feet even at 30 megacycles. This becomes progressively shorter, until at 300 megacycles they are about 3.28 feet long. These dimensions make it physically difficult or inconvenient to use beamed antenna systems on a moving vehicle. Therefore, communication is used without any attempt to confine the signal to the railroad right-of-way alone. If signals were sent 25 miles down the railroad track, they would be heard, would produce interference, and would tie up the channel frequency for 25 miles on each side of the railroad track in every direction for the entire length of the railroad system. This would result in a serious congestion of the radio-frequency spectrum in the more densely populated regions of the nation, which makes it advisable that higher frequencies in less heavily utilized parts of the spectrum be selected.

14 Microwave Radio Communication

The microwave portion of the radio spectrum, more generally known as the ultra high and the super high frequencies, show the greatest promise in the final and complete picture of railroad radio communication.

Prewar, it was common practice to consider frequencies higher than 300 megacycles as being in the microwave region. Microwaves were extremely difficult to generate or receive with conventional types of oscillators. It took tubes, such as the velocity-modulated Klystron type and, more recently, techniques, such as the Fonda-Freedman development using conventional tubes, to make the use of microwaves technically and economically feasible for many applications which lack of frequency space heretofore had made impossible.

In considering the use of microwaves for railroads, it has not been unusual to dismiss their possible use with the statement that they behave like light and therefore cannot work around a corner or beyond an obstruction, such as a hill, building, forest, or foliage. But no one is now justified in establishing any limitations as to what microwaves can or cannot do.

Instead, capable men can make them do what the application requires, if not directly, then in semidirect ways. Many of the limitations heretofore placed on microwaves are, in the final analysis, their greatest advantages.

Prior to World War II, other than in a relatively few special applications including amateur activity, most two-way radio communication in the world was conducted on frequencies lower than 300,000 kilocycles (300 megacycles). Frequencies higher than 300,000 kilocycles were not extensively utilized because of the so-called line-of-sight range limitation, and because ordinary vacuum tubes as well as radio circuit components would not always function in a satisfactory manner.

It became apparent to those who had faith in the potential value of microwaves that their use was feasible but that certain facts had to be appreciated. It was necessary to realize that as the frequency increased, inductive reactances became extremely high and capacitive reactances extremely low. So much so, that as far as AC was concerned the inductance became an insulator, and the condenser became a conductor. Also, that spacings between conductors or elements in a tube began to assume important amounts of capacitance, which had to be either utilized or compensated for. It also had to be appreciated that the phase or polarity might be different between the time a signal arrived or left one point and the time it reached another, particularly from the input grid to the output plate. This was true despite the tiny distance involved within the tube and the high speed of electron travel.

If an electric sine wave has a very high frequency, such as 5,000,000,000 cycles per second (that is, 5000 megacycles), at a speed of 186,000 miles per second it will have a complete phase reversal in one five-billionth of a second. For that short period of time, the 186,000 miles per second, representing nearly 12 billion inches of travel per second, means that such a wave has traveled only 2 inches. This is to say that wave energy at 5000 megacycles in 2 inches of travel will arrive 180 degrees out of phase, becoming positive instead of negative, or negative instead of positive. The exact speed of wave propagation involved is not 186,000 miles per second, since that figure only holds true in space. It is different in any medium other than air, such as inside a vacuum tube where its velocity is much less, depending upon the polarity and the voltages on its electrodes. This further aggravates this condition. This phenomenon is called phase shift or phase reversal resulting from transit time.

The Freedman-Fonda method uses conventional tubes where the transit time is made unimportant. The tube is operated in a conventional manner with normal spacing so that minimum interelectrode capacitance exists and normal-sized elements are used to handle normal amounts of

power. This shows unquestioned promise up to 1000 megacycles and has been successfully tested at this time in excess of 2000 megacycles. For frequencies exceeding 3000 megacycles, good performances have been obtained with velocity-modulated tubes using spaced grids correct for the general frequency band and tuned by adjustable cavities. In every case, both amplitude modulation or frequency modulation were feasible to provide and have been successfully tested. Since most microwave development, particularly recent tube developments, were largely financed by the Government for the purposes of national defense, much of the development cost has by this time been written off. It is reasonable to assume that material and production costs will be the principal rather than the minor part of the postwar equipment price, whereas heretofore development and research costs made up the larger portion of the equipment price. Therefore, microwave equipment may be expected to be low in cost because, as the frequency increases, the parts and the power required for communication through space become less.

Ordinarily, microwave frequencies may be susceptible to primary barriers produced by the curvature of the railroad. They are also affected by the horizon as created by the curvature and the topography of the earth. The topography, in the form of hills or valleys, tends either to increase or decrease the working range. A hill standing between two valley communicating points reduces the range, but there will be a great increase in range from the hill to either valley. A valley communicating point will provide good signaling with any point in the valley or anywhere as far as the summit of the hill rising from the valley. Beyond that it becomes problematical, being dependent on several factors. Hills provide outstanding ranges while valleys provide mediocre performance so far as communicating out of them is concerned.

Microwave frequencies may be susceptible to secondary barriers under some conditions, such as an absence of reflection or wave-guiding effects, or indirect ground conducting paths. These may be jungle, forest, heavy foliage, or objects larger than the wave length used and the beam width of the transmitted sector of transmission.

To overcome these primary and secondary barriers which tend to limit communication range and to provide the desired range in railroad applications, it is necessary to take advantage of three aids for microwave communications.

1. Make every station in the railroad system, either fixed or mobile, perform triple duty:

   (a) Serve as the radiotelephone transmitter and receiver to provide communication at its own location.

(b) Act as a booster station for any signal it picks up.
(c) Be an automatic relay and repeater station so that any signal coming in will be sent out again at full original strength to subsequent points within the limits of the railroad communication system.

2. Always remember that microwaves are a compromise between the behavior of a radio signal and the behavior of a beam of light even though it is invisible. Actually, it is radio's closest approach to light frequencies, being separated from it by the infrared spectrum.

When microwaves encounter a dead end or an obstruction in trying to travel infinitely onward in space, they behave much as a beam of light would behave when it encounters an object of like shape, size, and contour.

If natural conditions do not provide the desired reflections with correct angles for forward propagation, then it is conceivable to provide wayside reflectors of the correct shape, size, and angle of tilt, so that radiation from one direction is reflected at another angle around a corner or obstruction. The wayside reflectors might be permanently installed along the railroad right-of-way and require no further attention, since they have no parts to energize, wear out, replace, or adjust. Any loss of signal that may be caused by their employment in tunnels and highly tortuous areas can be compensated for by the repeater or booster station at the next point, which intercepts the signal again on another frequency.

3. Use frequency modulation so that if a station hears more than one point, due to overlap deliberately provided or exceptionally good conditions or intermediate proximity of one station in respect to others, only the loudest signal will be heard and the other stations will not manifest themselves simultaneously. This might also be necessary in order to cope with very small differences, due to circuit transition delays or differences in ranges between various stations heard. To use amplitude modulation would create an impossible condition due to heterodyning of two or more stations even where as much as 100 times signal-strength difference exists between them. FM makes it convenient to provide 100 per cent overlap in communication coverage to take care of any condition, including the inoperation of several relaying points in the system at any particular time.

The light-beam effect of microwaves when used in conjunction with wayside reflectors is theoretically inefficient. Only a small fraction of the energy will continue on, due to spreading and other losses. However, these reflections are needed only for very-short-range situations between communication stations, or where much curvature or tunneling exists in a short stretch of distance. Very little actual energy is required at a radio receiving point. Modern FM receivers can work with signals having a strength of less than a few millionths of a volt per meter. This is within the realm of feasibility for the short distances involved between stations, particularly since transmissions are usually focused and concentrated toward the reflector, being feasible to do so because of the narrow lane of the railroad. The signal falls off as the inverse square of the distance for any radio communication. It is a small amount for a short distance and diverges to a larger amount as the distance increases.

Computing Range for Individual Microwave Station. Ordinarily, the

service area each unit covers will be the distance between any two communicating points, whether fixed and mobile, fixed and fixed, or mobile and mobile. Except in the more isolated parts of the United States, a study of railroad layouts indicates that there are railroad stations, towers, and special facilities where a combination zone communication relay station can be provided at least every 5 miles. At each point, the signal can be boosted and given an additional horizon of distance as well as provide local communication. Between these points if the horizon is obstructed for short distances, due to curves, hills, or tunnels, reliance is placed on natural reflection, wave-guide effects of the topographical contour, guided assistance from railroad trackage, wayside wires, and local conditions of moisture. If that is insufficient, then wherever a dead spot is found, wayside reflectors may be installed along the railroad right-of-way. These wayside reflectors behave like reflecting mirrors, receiving the beamed microwave signal at an angle corresponding to the trackage ahead or behind. To visualize this behavior, imagine that a locomotive on the track half a mile away from an obstruction wishes to communicate around or behind it. The signal from the locomotive may be a beam 10 degrees wide. The wayside reflector at the obstruction or curve may be only 3 feet in size. A small but definite amount of energy will strike the reflector and be directed onward until it reaches a relay station where its power is restored to a strength comparable with the original amount. Wayside reflectors will be most useful if beamed transmissions are employed. Nondirective transmissions might not have sufficient concentration of energy to perform this task satisfactorily. The larger the reflector and the higher the frequency, the sharper can the signal be beamed and controlled.

The microwave spectrum, aside from its other advantages, makes possible directive or focused communication. Instead of signal radiation in useless directions above, below, right, left, or at any intermediate angle, it is beamed in the area communication is desired. This makes possible a concentration of power that can be 100 to 1000 times greater than nondirective lower-frequency radio operations. Since the wave lengths involved are in the order of inches as compared to feet, yards, or even miles on the lower frequencies, it is possible to provide reflectors substantially larger than several wave lengths.

Microwaves also contain a wealth of frequency spectrum available for many applications and stations, such as the use of frequency modulation with optimum deviation ratios. This provides additional range, signal strength and quality, and ability to override interference noises, as well as to utilize the full inherent capabilities of the receiver. For example, on microwaves, a receiver operating at 2000 megacycles might have an

inherent band-pass of 1000 kilocycles (1 megacycle). If AM is used, the radio signals might only occupy 10 kilocycles, so that only 1 per cent of the receiver's capabilities are utilized. With FM, a frequency swing or deviation ratio (sometimes called modulation index) can be used, so that for normal voice the frequency swings an amount that fully occupies the most sensitive part of the entire receiver's inherent band-pass.

There are differences of opinion as to what this really means. Some claim it is equivalent to pulsing transmitter power, thereby gaining much signal intensity at the receiving point that only an enormously more powerful transmitter could duplicate. Others claim it is impossible to evaluate it, since it would mean "getting something from nothing." However, it is obvious that utilizing the receiver's full capabilities is going to do more than utilizing only a portion of it. High deviation ratios are advantageous and, when coupled with the other advantages of microwaves, mean that FM will produce phenomenal results equivalent to many times increased transmitter power on lower frequencies.

Increased range means to us increasing the received signal strength to provide good intelligibility at increased distance. For all we know, even weak signals may extend to the limits of the earth for the direct ground component and to the limits of the universe for the direct or indirect sky component. We do know that the signals are capable of traveling great distances, even more than that required as a minimum in railroad applications. But whether such signal is loud enough and clear enough to be understood at the required distance is largely dependent on the signal-to-noise ratio at the receiving points. So long as the noise from outside and inside the equipment is weaker, the signal can be utilized effectively, regardless of distance, by merely employing more amplification within the equipment. Increase in amplification is some cases may be accomplished by driving each tube a little harder or by adding more tubes in the receiver. (Most tubes do not utilize their full amplification; for example, there are tubes which have an amplification factor of several hundred and even thousands that may be using less than 5 per cent of their amplification because the signal-to-noise ratio prevents doing so.)

Amplitude modulation often is unable to utilize the full capability of a multistage amplifier because of high noise levels which accompany it. FM can definitely discriminate against such noise and bring in more signal in proportion to noise. A small improvement in signal-to-noise ratio is much more helpful than a great increase in transmitting power. So long as the signal-to-noise ratio is favorable, a few watts of transmitting power may be equivalent to hundreds of watts when the receiver can utilize more of the amplification it can provide but normally is unable to use.

The full capabilities of receiver amplification cannot even be fully utilized with FM, but it is possible to do so to a much greater degree than with AM. Microwave equipment as required for railroad applications can function with what may seem excessively low power, for example, a fraction of a watt. It can, of course, function better with more power, but unless enormously more, the difference may not be worth the expense, increased continuous power drain, and subsequent maintenance. Instead, great carrying power comes from its very high frequency—a billion or more cycles per second. This increased frequency of an electromagnetic wave, together with focused antenna radiation, FM, and high signal-to-noise ratios make it extremely efficient as compared with lower-frequency equipment.

If stations at towers, terminals, and elsewhere are spaced at an average distance of 5 miles or thereabouts, as they frequently are, a train will never be over 2½ miles from some wayside station available for communication or signal boosting. In addition, even the mobile stations can perform automatic relaying or signal boosting for any signals picked up when they are not themselves the origin or destination of the communication.

In computing transmitting range, it is convenient to use the minimum by basing it on the optical and radio horizons. For reasons given below, it will be exceeded in practice, so that as much as 100 per cent or more overlap will actually exist in most cases along the railroad. The maximum possible optical range in miles, for perfect vision under ideal conditions of visibility and an unobstructed horizon other than that caused by the curvature of the earth itself, is equal to 1.225 times the square root of the observer's elevation in feet, plus 1.225 times the square root of the observed's elevation in feet above the earth's same surface. The following example might exist in railroad service:

Observer in Tower	Feet
Rise of land over average ground level	12
Height of floor of tower room above the ground	19
Height of observer's eye above tower-room floor	5
	36

Square root of 36 = 6
1.225 × 6 = 7.35 miles horizon.

Observed Atop Train	Feet
Rise of land over average ground level	0
Rise of roadbed over general land level	2
Height of ties and rails	½
Height of freight car	11
Height of observed's eye above top of freight car	5½
	19

Square root of 19 = 4.35
1.225 × 4.35 = 5.33 miles.

Combined horizon of both points = 12.68 miles.

This means that the observer can theoretically see a maximum distance of 7.35 miles before the curvature of the earth blocks his vision. At sea, the eye sees the horizon as a circle with the masthead of another

ship or smoke from a ship beyond the horizon looming over the edge of the circle. In practice, this maximum optical horizon is seldom realized except possibly at night with a strong distinctive light. Vision is not perfect, as fog can reduce it to zero, or mist can reduce it to some intermediate distance, while darkness also brings it down to zero unless illumination is employed.

However, when very-high-frequency radio is used, the minimum radio range is always greater than the maximum optical range because of additional phenomena not available for optical conditions. The effect is comparable with the earth's being of larger dimension. If the earth were a third greater in radius, the circumference would be proportionately greater. The horizon would extend proportionately farther because of reduced curvature that would result for a given distance. This effect in range actually takes place because, instead of traveling in a truly straight line horizontally, the signal actually curves slightly with the curvature of the earth to give it an extended horizon. In addition, the signal never falls off or terminates abruptly at the horizon. It has some dispersion beyond the horizon, but the signal then becomes less usable. There still remains a useful residual signal beyond the horizon, depending on the receiver sensitivity and the signal-to-noise ratio. In radio work, therefore, instead of using 1.225, the optical constant, 1.4 is used as a minimum constant, which in practice may compute to a constant as high as 2.0 or even greater when good ground conductivity, railroad track, or other transmission and reception facilitating paths exists. Basing it at the minimum figure of 1.4 for the elevations discussed in the optical case, this computes to:

Observer's Location (Transmitting Point)	Observed Location (Receiving Point)
$1.4 \times 6 = 8.4$ miles	$1.4 \times 4.35 = 6.1$ miles

These total 14.5 miles for minimum radio range as compared to 12.68 miles for maximum optical range. It can be further demonstrated in actual practice with great constancy that the radio range is not dependent on the optical range. The latter is merely a convenient reference point. Actually, it is a minimum value and is approximate, since it makes no allowance for anything that promotes ground conductivity, reflection, or guided communication.

These computations are about the same for both very high frequency and microwaves. Using the same method of computation, the reader can determine optical and radio ranges for any location and condition. In areas of great aridity and little ground conductivity worthy of mention, such as a desert during a hot sunny day, minimum radio ranges are con-

ceivable. These could be even less than the optical horizon. Then the railroad track and wayside wires, either or both, are of utmost importance to offset that condition. This is where the railroads have a great advantage over highway or cross-country applications for space radio. When, in September, 1944, a storm of hurricane force brought down the landlines in New England, it was reported that radio performance was reduced in range and signal strength. As the landlines were gradually restored, performance began to increase markedly for beyond-horizon ranges. This is logical. Personnel attached to geophysical and geological exploration groups have reported that, in the very arid areas of Arizona, horizon radio ranges could not be maintained. This is also logical, since no helpful path exist there, such as wires or railroad track. AM was used instead of FM and low frequencies. These facts serve to confirm that direct comparison of radio ranges with optical conditions is a faulty relationship even on microwaves.

Maximum ranges will be maintained when one or both stations have great horizons. These add together, regardless of what part each contributes to the total. Suppose a vantage point on a railroad system gives a total elevation of 2500 feet with respect to a train in the valley, which has a total height of only 16 feet. The ranges compute to:

	Maximum Optical Miles	Minimum Radio Miles
Vantage-point horizon	$= 1.225 \times 50 = 61.25$	$1.4 \times 50 = 70$
Train-point horizon	$= 1.225 \times 4 = 4.9$	$1.4 \times 4 = 5.6$
Total optical	. . . . . 66.15	Radio 75.6

Anything tending to reduce optical range is usually advantageous to radio range and signal strength, since it might be due to fog, rain,.sleet, snow, mist, or haze. All of these forms of moisture tend to improve electrical conductivity. Very heavy rain or sleet coming down as virtually a solid mass, enough to ruin all visibility, may also have a detrimental influence on microwave communications, but it will never be total. In part, the resultant drop in signal will be offset by the improved ground conductivity obtained by the moisture.

Radio Towers to Increase Horizons. Windmill type steel self-supporting triangular towers are useful in extending the radio horizon. They are climbable and inexpensive to purchase and to erect. Such towers are useful for relay stations if other vantage points are not available. They can be purchased and erected for a cost that may be less than $5 per running foot of height. One manufacturer quotes the heights and weights shown below, and to those the radio horizon range has been added, using 1.4 as the constant.

Height Feet	Weight Pounds	Independent Horizon Miles	Combined Horizon (Two) Miles
20	255	6.25	12½
27	341	7.3	14.6
40	533	8.85	17.7
53	759	10.2	20.4
67	1,033	11.46	22.9
80	1,413	12.52	25

A microwave system using 80-foot towers, costing less than $500 each, completely installed, would have a horizon of 25 miles for any pair of such adjacent points on the same ground plane. Any elevations at either point would increase this range.

To conserve weight, cost, space, and erection labor, triangular towers are recommended. They are fully as satisfactory as four-legged towers. In some respects they are better than four-legged towers because they are designed to withstand winds exceeding 70 miles per hour without distortion of frame. U-channel leg sections are used instead of 90-degree angles for extra strength and rigidity.

Zone Communication and Repeater Station. To extend the microwave railroad system for the required over-all distance of a railroad division or even a complete railroad route, three plans, developed in their present form in November, 1943, are presented here.

PLAN 1. This plan is built around a standardized equipment package comprising two transmitters TA and TB, and two receivers RA and RB. One channel of communication comprises two radio frequencies: frequency A, which might be 2800 megacycles, and frequency B, which might be 2900 megacycles. These equipments are designed for use on the front or rear of trains, towers, railroad stations, and terminals, wherever communication is required in fixed, mobile, or portable applications. Ordinarily, these stations are sufficiently close enough so that none is beyond the limits of a radio horizon with respect to adjacent stations in either direction. If they are not close enough together, then special unattended automatic relay stations using similar or identical equipment could be used.

As illustrated, the engineer of a passenger train wants to talk to his division headquarters 50 or more miles away. He can establish communication on either TA (transmitter frequency A) or TB (transmitter frequency B), or on both. Assume he uses TA. The nearest station happens to be a tower, which receives the signal on RA (receiver frequency A). Whatever receiver RA picks up on frequency A, it can receive locally, or it can automatically and immediately retransmit on TB (transmitter frequency B). At the next point, whatever it picks up on receiving frequency B, it automatically retransmits on transmitter frequency A. Thereafter, it

alternates between any equipment within range until it reaches the desired destination. The receiving communication points do not know whether it will come in on RA or RB.

Both receivers are operating into a common loudspeaker, so that either signal frequency or the loudest signal can come through. As a train changes its location while in motion, it causes the signal to change from RA to RB, or vice versa. This common loudspeaker takes care of that situation. The abruptness and electronic rapidity with which this action takes place is ordinarily undetectable to the human ear. Front-to-rear communication on the same train can be conducted directly. If this should ever happen not to be the case (because a train longer than any now in existence is winding around several curves at one time), then it would undergo automatic relaying as for distant communication and get through between both points in such manner.

PLAN 2. This plan operates similarly to Plan 1, but uses only half the equipment in the nonmobile stations. Every station is staggered with respect to the adjacent one in either direction. Every other station has TA/RB with the alternate ones having TB/RA. The result is the same except that the mobile station should use the correct frequency or, if in doubt, should initiate communication on both frequencies simultaneously. The advantage of Plan 1 over Plan 2 is the possibility of using a smaller number of stations. Also, if one set of facilities should become inoperative, the other set could function. Also, one set can be used in one direction while the other is used in the opposite direction. This would eliminate the possibility, should it manifest itself, of formation of an oscillating chain of signals coming back again and going out again in an endless circle, in addition to moving ahead in both directions.

PLAN 3. This dispenses with some of the special relay stations employed at certain curves or tunnels. It relies on using all the points that need and have communication to pass on and automatically boost the signals. Wherever the curvature and the topography along the railroad retards or prevents microwave signals passing beyond such areas, special wayside reflectors working on the beam-of-light and reflecting-mirror principle will receive and reflect the signal onward with the correct angles to clear radio obstructions. While such reflectors can only receive and pass on exceedingly small percentages of the total energy available, they can pass on enough signal to actuate the next station available for relaying or boosting.

Microwave Antennas on Trains. Trains have limited external space for antennas without encountering physical interference. The antenna on microwaves can be the same as for lower frequencies except that the size becomes very small. Because the antenna is of small size for a half-

wave length, it can be made up in arrays of directors and reflectors to provide considerable directivity of transmission and concentration of power in a desired direction. If desired, it can do even better than that. A parabolic reflector of dish shape might be used, with total size no larger or much different in appearance than the silvered mirror of a locomotive headlight. Such a shape and dimension gives a beam width of about 20 degrees, conic fashion. Larger reflectors for the frequencies discussed in the plans above give even narrower beam widths. A 3-foot reflector gives about 8 degrees beam width on such frequencies.

In addition to the savings in space and size for railroads, such an antenna design has the following advantages:

1. Confines communication to a narrow sector, so that the major propagation is confined largely to the railroad right-of-way. This advantage also conserves frequency utilization. It makes it possible, if necessary, for the same frequencies to be used by other services only a short distance away, or to be used in other directions and sectors in the same general area. Railroads do not necessarily need an exclusive channel in all directions to have interference-free communication. This further simplifies frequency requirements for the railroads because of:

   (a) Large amount of available channels in the microwave spectrum.
   (b) Availability of all these frequencies at points beyond each horizon.
   (c) Beamed or focused transmissions occupying a narrow conical or elliptic sector in space along the railroad lane, with minimum overlap beyond the confines of the railroad right-of-way.

2. Makes difficult and largely impossible the reception of signals by unauthorized receiving points not along the railroad right-of-way or close thereto. It is also inconvenient for such unauthorized persons to provide the specific equipment for the purpose.
3. All the energy is concentrated principally in the desired sector of transmission rather than dissipated in all spherical directions above the horizon. This is equivalent to increasing the power as much as 100 to 1000 times, depending on the beam concentration employed. This results in greater ranges and better signals and conserves input and output power.

Although the signals are beamed, limited lateral distances may be covered until the radiated beam diverges enough to encompass the entire width of the railroad property. Only the main lobe is fully directive. There are also minor lobes, which, while very inefficient and usable only a short distance, are more than adequate to cover the laterally extending areas in other directions near by and to fill in the blank spots of the main lobe for several hundred feet from the transmitting source. This is true even if the signal is directly in back of the reflector. The fact that there are walls and enclosures very close to railway tracks does not mean that the signal is confined and unable to get beyond such restricted spaces. Tests made in large reinforced steel and masonry structures, with many walls

and partitions, provided good communication, even though actual line of sight was obscured for a distance of over 200 feet. In fact, the directional antenna could be aimed in any direction and still produce enough reflections to permit reception of optimum signals. This was true even when the doors and windows of the room were closed.

For front-to-rear or end-to-end communication, the railroads do not desire ranges exceeding 5 miles, in order to confine transmissions to the interested parties. Here microwave equipment may be especially feasible.

Equipment Availability. An objection arising in the past has been that while microwaves admittedly have many interesting and useful applications because of the adequacy of the frequency spectrum, the equipment has not been available to prospective users. Prior to World War II, microwave equipment was largely under laboratory development, and ideal tubes had not yet been developed. Microwaves gained supremacy in connection with military applications during World War II. The Fonda-Freedman development has simplified the vacuum tube problem where that has been necessary. Mass production methods have been developed and are in effect for producing the velocity-modulated type of tube. Several other developments by various firms are now well under way and promise a wide selection of tubes and tube techniques suitable for microwave communication.

The Halstead Traffic Communications Corporation has equipment under test or already developed for the following frequencies:

156 to 190 megacycles	10 watts.
200 to 270 megacycles	10 watts.
300 to 400 megacycles	5 to 10 watts.
2000 to 3000 megacycles	5 to 10 watts.

While companion AM types are available, this company is concentrating on and recommending frequency modulation in every case. The original price quotations are approximately the same as for other frequencies. They are suitable in a choice of deviation ratios. Frequencies below 200 megacycles are crystal-controlled; those above that frequency employ special concentric-line oscillators with automatic frequency-drift compensation.

A choice of equipments and techniques is assured by several firms for the postwar period at normal cost to interested users.

15 Functional Equipment Comparisons

Several different types of induction radio and space radio communication facilities have been discussed in this chapter. The functions of all these types are evaluated and compared here in a table. There are great variations in some cases among the manufactured types. The comparisons

can be only approximate. Prospective purchasers should contact various firms to get the latest information on new developments. In general, the following variations may be expected. These will affect costs and in some instances also performance.

1. Whether manufacturer builds equipment exceptionally rugged, possibly more than necessary.
2. Whether equipment is custom built, semicustom built, or mass production.
3. Whether the equipment is special for a particular application, or whether it exists for other fields of application also.
4. Whether used on a lower or a higher frequency.
5. Whether customer requires very special provisions as to power supply or equipment casings.
6. Whether customer makes the sale easy or difficult to consummate.
7. Whether patents are involved requiring extra royalty payments.
8. Whether maximum, normal, or minimum power will suffice.
9. Whether equipment will be subjected to abuse.
10. Whether equipment will be subjected to the elements.

Great variations in cost may exist between custom-built and mass-production equipment. A custom-built unit in small quantity might cost $3000, while a semicustom-built unit might be $1000, and a mass-production unit, $200 to $500. It is even conceivable for equipment to exceed these extremes in either direction. Development, field engineering, and sales costs must be absorbed, either in high cost per unit or by volume. Frequently a small organization specializing in a specific branch of two-way communication is able to reduce or eliminate the development cost as a result of other developments that can be modified or are similar enough to what is required. Material costs of the component parts frequently do not constitute the major part of the purchase price. The purchaser is in a position to control the price by the quantity and manner of consummating the transaction, particularly during normal times when competition exists.

16 Typical Railroad Communication Problems

It is apparent that the use of only one type of equipment or technique to meet all the communication problems of all the railroads is largely impracticable, particularly for main-line operations where trains travel many hundreds of miles on a single trip through both populated and isolated areas, encountering every form of terrain and weather.

Some of the conditions to be met throughout sections of the United States are described here and are illustrated with reproductions of photographs furnished by the Association of American Railroads.

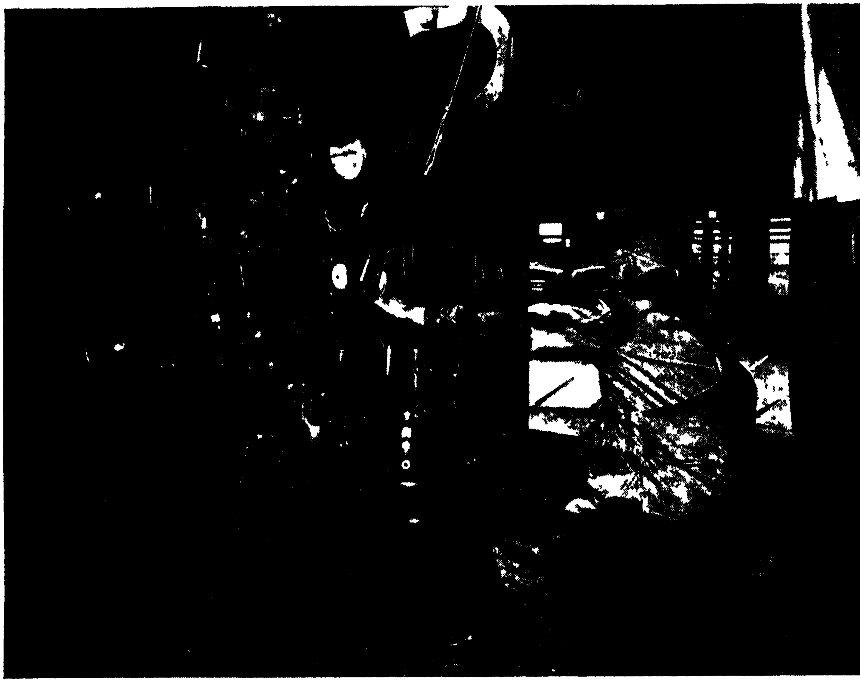
It is suggested that readers also study the special communication package designed for busses and trucks, discussed in Chapter Fourteen.

Functional Comparisons*

Consideration	Induction Systems	Medium Frequency	VHF	Microwaves
Typical equipment	Aireon Mfg. Corp. Halstead Union Switch & Signal	Harvey-Wells Jefferson-Travis Harvey Radio Lab. Hallicrafter	Motorola FM Link FM G.E. FM Bendix AM Halstead AM/FM	Halstead Special groups
Usual power outputs (mobile stations)	10–50 watts	10–25 watts	25–50 watts FM 10–25 watts AM	5 watts or less
Performance on AM	Poor or fair	Fair	Good	Good
Performance on FM	Good	Anticipated good	Excellent	Excellent
Preferability of FM	Yes	Yes if permitted	Yes	Yes
Deviation ratio feasible for FM	Anything above unity	Anything above unity	5 to 1	10 to 1 or more
Average noise level	High on AM; low on FM	High on AM; low on FM	Low	Very low
Approximate cost	\$500–\$2000	\$300–\$1000	\$500–\$1500	\$300–\$1000
Effect of two AM stations simultaneously on same frequency	Howl	Howl	Howl	Howl
Effect of two FM stations simultaneously on same frequency	Loudest takes control	Same	Same	Same
Intelligibility on AM	Poor to fair	Good	Good	Good
Intelligibility on FM	Good	Good if used	Excellent	Excellent
Effect of static and lightning	Bad with AM; better on FM	Same	Slight	Absent
Effect of RR curvature	None	Variable	Variable	Variable
Normal two-way ranges, train to train without wayside wires	About 300–600 feet	Erratic and variable up to 200 miles	Variable up to 25 miles; usually 10 miles	Same as VHF usually
Same as above but with wayside wires	Various up to few miles (not ideal)	Same as above	Same as above	Same as above
Range two-way between train and fixed point	50–100 miles or even farther	50–200 but very erratic	Depends on horizon; about 25–75 miles; less on AM	Depends on height and curvature; about same as VHF
Need for relay or repeater stations	Desirable every 50–100 miles	Unfeasible	Desirable every horizon	Desirable and very feasible every horizon or farther if reflections good
Directed communication	Naturally follows wayside wires, including those in undesired directions; little radiation elsewhere	Unfeasible	Partially feasible	Very feasible
Effect of wet or bad weather	Less favorable due to insulation leakage on wayside wires	Less favorable	Best performance (due to better earth conductivity)	Best performance (due to better earth conductivity)

Consideration	Induction Systems	Medium Frequency	VFH	Microwaves
Antenna provisions	Inductive loop or cable	Horizontal wire or loaded vertical rod	Quarter-wave fishpole	Various; wave guides and reflectors also feasible
Number of tubes for complete station	About 18–20	10–12	18–20 FM; less on AM	About 12
Spectrum in terms on frequency	Usually between 10–200 kc.; FM used on higher and AM on lower frequencies; on FM feasible even higher	2000–3000 kc.	30–40 mc. 116–120 mc. 156–162 mc.	300–400 mc. 1000 mc. region 2000–3000 mc.
Room for service expansion	Limited	Small	Moderate	Considerable
Performance night vs. day	Quite consistent	Farther at night with intermediate skip distances; more interference at night	Quite consistent	Quite consistent; temperature inversion may cause extended ranges in warm weather over moisture areas
Performance winter vs. summer	Unchanged	Works best in winter when less static	Unchanged except gains from presence of moisture	Same as VHF
Effect of intervening hills and mountains	Unchanged	Erratic	Erratic	Erratic but may reflect through them if contour favors this
Need for elevated antenna to extend range	Nil	Antenna length may be more important	Important	Important
Size and weight less special cases for RR conditions	2–6 cubic ft. 50–200 lbs.	2 cubic ft. 50–100 lbs.	2 cubic ft. 100 lbs.	1½ cu. ft. 50 lbs.
Signal-to-noise ratio	Poor to fair on AM; fair to good on FM	Poor to fair	Good	Very good
Critical design	Not critical	Not critical	Critical	Very critical
Effect of transit time on phase and polarity	Minor	Minor	Small	Considerable
Equipment availability	Fair	Good	Good	Poor to fair
Interference to wayside circuits	Impossible on same frequency; must be isolated about 20 kc.; more with FM exceeding unity deviation ratio	Nil	Nil	Nil
Means to maintain frequency stability	Tuned circuit or electron-coupled oscillator	Crystal	Crystal	Special concentric-line oscillator; automatic frequency-drift compensator; receiver AFC, etc.
Effect of tunnel	None if wire present	Very poor	Poor	Usually functions
Receiver band width	Below 5 kc. except for FM which depends on deviation ratio	Below 10 kc.	40 kc	Variable up to a megacycle on 3000 mc.

* These comparisons are based on the average opinions and experiences of several railroad and radio organizations. Where limited experience exists for some of the situations indicated, their anticipated behavior based on past performances in other radio communication services is given.



THE STEAM LOCOMOTIVE
A Norfolk and Western Railway engineer at the controls in the cab of his locomotive. (Courtesy Norfolk and Western Railway.)

While the communication problems of railroads are much easier to solve than those of the intercity highway vehicle, the problems of providing positive communication, regardless of location, distance, time, or weather, for local, metropolitan, and long-distance ranges in the more isolated sections of the country may be very similar.

Steam Locomotive. The communication problems to be solved in the case of the steam locomotive are noise, draft, soot, heat, cold, exposure, vibration, and shock. The engineer must concentrate on what lies ahead and on the general operation of the locomotive and train.

The loudspeaker should be so located that voice signals will reach the engineer with minimum loss or confusion with other noises. The speaker cone or diaphragm should not be directly exposed but instead should be protected by double-entrant construction.

The microphone should be within easy reach of the engineer. The entire equipment should be operated with only one hand or, when desirable, without using the hands. The microphone should be of the insensitive type, requiring fairly loud and close-up conversation, so that local noises in the engine while in motion will not override the voice signals. If

the engineer wishes to keep his hands free during conversation or have much greater freedom of movement, he can use a flexibly supported or gooseneck type of microphone suspension of ample rigidity to prevent accidental displacement and a throat-type microphone, or a microphone and headphone harness. The throat-type microphone is popular in aviation where the pilot has to keep his hands free for plane operation and his eyes concentrated on his instruments during blind flying. However, throat-type microphones are not particularly comfortable to wear nor exceptionally good in reproduction in the case of persons having fatty throat tissues or extremely little vibration of the throat area with speech. In general, a handset is preferred, incorporating a push-to-talk button on the handle to energize the transmitter, with the equipment in receiving or standby condition when the button is released. The earpiece is similar to the modern French-type handset employed in ordinary telephone service.

The equipment proper should be enclosed in a cabinet protected against damage by water, soot, dust, and moisture, with adequate provisions for indirect ventilation or heat radiation to prevent the tubes and equipment from overheating within the casing. In extreme cases where not even ventilating louvres are permissible, the excess heat developed by the tubes in the equipment can be removed by blower and/or metallic conduction and radiation. This should not be necessary in rail service, being generally required on small vessels which are apt to be awash in terrific seas and storms where the equipment may be inundated at intervals.

The equipment may be placed wherever desired, consistent with available space in the cab or on the tender. The apparatus is usually remotely controlled by the engineer. The transmitter-receiver unit should be close to the antenna in order to minimize transmission-line losses, if this is convenient.

The power cable should be as short as possible with respect to the distance between power source and the equipment. If this is not convenient, then a heavier cable with a lower ohmic resistance per unit length should be used. The voltage drop is equal to the ohmic resistance of the two wires in the cable, multiplied by the current in the line as measured in amperes. It will not be less, probably will be more, if only a single wire is used with ground return through the locomotive metal structure. It is good practice to keep the voltage drop in the power line to below 10 per cent in every case and preferably below 5 per cent.

Shock mounts should protect the equipment against combined shock and vibration in all planes. They should protect against shock equal to six or more times the weight of the equipment they support and should

THE DIESEL LOCOMOTIVE
Engineer at controls in the cab of "Santa Fe" diesel-electric freight locomotive (Courtesy Santa Fe Railway.)

completely absorb all resonant vibration at frequencies up to at least 1400 cycles per minute.

Diesel-Electric Locomotive. The communication problems in the case of the diesel-electric locomotive may be an overhead rumble from vibrating steel as the locomotive moves down the track at high speed and electrical interference from rotating machinery and sparking contacts.

Such a system should utilize frequency modulation to minimize electrical interference with radio reception The electrical interference can be further minimized by shielding and bonding for elimination of

contact noise and circulating ground currents caused by unequal ground-path lengths which create a difference of potential between them. Movement of one metal surface with respect to another causes potential differences and electrical noise. Straps or jumpers are used between two such surfaces to provide a good electrical bond. Changing the points of grounding may help. Filters made up of inductance or capacitance, or a combination of the two, are helpful in correcting electrical transients that produce interference.

A good squelch circuit should be incorporated in the radio receiver, so that normal interference and noise levels will be unable to operate the squelch and be reproduced in the loudspeaker. Only a signal having sufficient strength to be useful for reception should be allowed to operate the squelch and permit communication. This signal should be strong enough to override electrical and acoustical noise during actual communication. The net result is that the operator of the mobile unit has excellent communication for all practical purposes. During standby, the background noise is not reproduced because the receiver is sufficiently squelched. During communication, the signal is stronger, and the noise does not manifest itself in the background. The loudspeaker operation is therefore quiet during standby periods.

If required in unusual cases, a simple acoustical treatment, consisting of weatherproof and fireproof acoustical paneling, can be installed on the wall or ceiling of a cab, which ordinarily takes care of excessive overhead rumble.

Caboose. In the caboose, the problem is primarily to provide a suitable power source to operate the radio equipment. This cannot be merely a wheel or axle-driven generator, since the caboose may not be in motion when the communication is required.

The caboose requires a storage battery and the means for recharging or floating the battery. The charging system should have an output equal to the maximum transmitter load during voice transmission, or it should be about three times the normal receiver-standby power drain, so that there is an excess of power to build up the battery charge while the caboose is under way, which will make up for the battery drain when not in motion. The charging generator should be an axle or wheel-driven generator, using a wheel frictionally or otherwise engaged to a wheel of one of the caboose trucks.

When power is provided for radio equipment in the caboose, the demand arises for electric lighting and other electric appliances which were not available when power was lacking. With the advent of radio, what was previously a luxury for the men in the caboose suddenly becomes a necessity. It should be feasible to accommodate some power for

THE CABOOSE

The conductor makes an entry in his trip log of readings of the air valve on the wall. (Courtesy New York, New Haven and Hartford Railroad.)

such purposes. The charging system should have a dependable current-voltage regulator to prevent overcharging the battery should the caboose be in motion more than normally expected during periods of time when there is little power drain, such as little transmission during perfect daylight weather.

Space and placement for antenna and equipment is not likely to be a problem in the coboose.

Tunnel. The tunnel shown in the accompanying illustration presents one of the most difficult problems that can arise in railroad communication service, for the following reasons:

1. The tunnel is barely large enough for a single train and has only one set of tracks. Traffic in both directions use the track and tunnel at different times.
2. The track takes a pronounced curve immediately after emerging from the tunnel. This is unfavorable for microwave propagation unless there are special repeater or reflector provisions.
3. The tunnel is in an area of rock having poor conductivity, which is very poor for medium-frequency operation.

THE TUNNEL
A diesel-powered merchandise freight train of the Southern Railway emerging from a tunnel (Courtesy Southern Railway)

4 The amount of overhead clearance for antenna purposes is limited in the tunnel, making it inconvenient to locate the antenna at any appreciable height above the roof of the mobile unit without encountering physical interference.

5 No wayside wires appear to be near the tunnel, thus creating a problem if induction radio were used.

To cope with these conditions, induction radio systems may be used if the tunnel is of short length and there are some conducting wires actually present, such as a lighting circuit (even though not seen in the illustration) The track is always dry in such a location ordinarily and will make a good conductor. It is feasible to provide a special wire in the tunnel for this specific purpose and for other purposes, similar to the experimental installation of the Halstead induction radio system used in the Queens Midtown Tunnel in New York City.

Medium frequency will probably be unsatisfactory altogether.

Very high frequency will probably function in the tunnel for all or a substantial part of the distance because of the ground conductivity and transmission paths resulting from the presence of railroad trackage and possibly wave-guide effect

RAILROAD CURVATURE
Freight train pulling through a mountain pass (Courtesy Denver and Rio Grande Western Railroad)

Microwave equipment will probably require auxiliary propagation aids in meeting these conditions as the tunnel has poor alignment with the trackage, which curves outside the tunnel. The use of natural reflection by approximation of the beam-of-light and mirror effect would probably be unsatisfactory because of the contour, shape, and dimensions apparent in this specific illustration. It is probable that an automatic repeater station would be needed at the tunnel mouth to relay the signal in the desired direction at the end of the tunnel. Inside the tunnel, microwave signal energy should have little difficulty to continue onward where the tunnel is not straight. The railroad trackage is helpful for microwave propagation. Outside the tunnel, the open space and the steel bridgework (shown in the illustration) should aid in maintaining improved communication and good signal strength at that area. The performance will be more satisfactory if FM is used instead of AM to permit maximum signal-to-noise ratio to overcome the attenuation of the tunnel. A good automatic volume-control circuit in the receiving equipment at communication points will be of great value for this situation to maintain average signal level.

THE MOUNTAIN PASS
A Northern Pacific freight train passing through Bozeman Pass, Montana (Courtesy Farm Security Administration.)

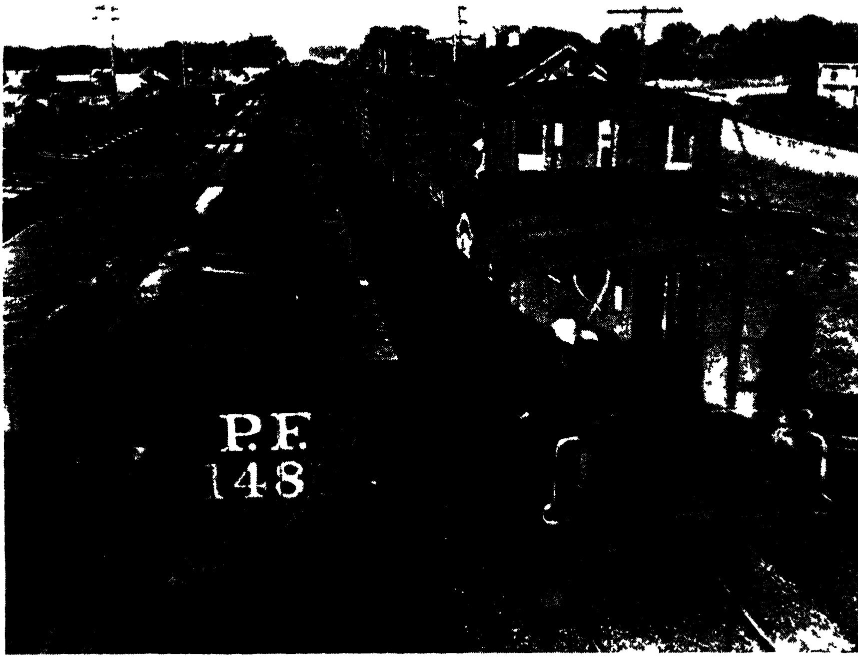
Railroad Curvature in Obstructed Areas. The principal disadvantage in railroad curvature in obstructed areas is an obstructed horizon and the blanking effect of abrupt hillsides containing much rock and ground of poor conductivity. The advantages are the metallic transmission path of the railroad trackage and the fact that the train as a whole is sufficiently long and continuous to provide additional guidance to, around, and beyond the curve.

In the illustration, more than ten wires are shown along the railroad right-of-way, closely paralleling the railroad track. This should be of value in further providing a good path around the curve and through the mountainous pass. The hills are of such contour as to make possible some useful reflection effects for very high frequencies and microwaves. At this particular point, the river or stream alongside the trackage should be of great value in improving the ground conductivity, making possible radio coverage even where the horizon is obscured.

Induction radio should be entirely satisfactory.

Medium frequency will probably function poorly with erratic abnormal ranges at night from sky-wave reflections.

Very high frequency should provide good communication most of the



TRAIN-TO-TRAIN
The southbound "Blue Streak," fast merchandise train of the cotton belt, passing a northbound trainload of California perishables near Brinkley, Arkansas. (Courtesy Southern Pacific Railroad)

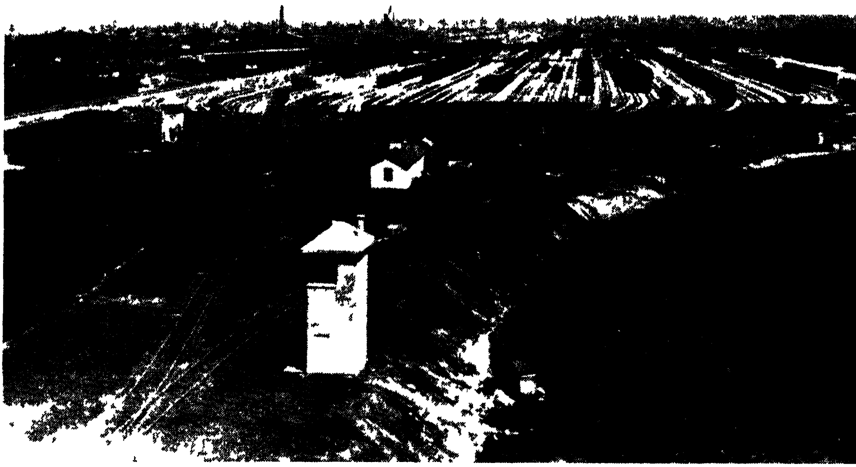
time. If FM is used, it should maintain reliable communication with great constancy front to rear.

Microwave systems may require a propagation aid, such as an automatic repeater or wayside reflector. If the automatic repeater is located on top of one of the hillsides, the antenna may be positioned to have a clear optical and radio path with respect to the railroad track as well as an increased horizon extending great distances, conceivably 50 miles or more.

This type of terrain should have low noise levels and high signal-to-noise ratios. Some reflection should be possible from the sides of the freight cars where curves in trackage are present.

Mountain Pass. In the mountain pass depicted in the accompanying illustration, there is the disadvantage of physical barriers substantially higher than the railroad right-of-way. The advantages are the three crossarms carrying wayside wires, multiple railroad tracks, and the fact that the curvature is not too excessive for such an area.

Induction radio will function satisfactorily.



HUMPYARD OR CLASSIFICATION YARD
Chicago and Northwestern Railroad (Courtesy Pravisco Yard, Chicago, Ill.)

Medium frequency should be satisfactory except for some attenuation and signal variations as the train travels through the more recessed areas.

Very high frequency should function very well most of the time because of the high-elevation wayside antenna possibilities as well as the propagation aids presented by the hillside reflections and trackage. If FM is used, it is believed that front-to-rear communications will virtually always be possible with satisfactory performance levels.

Microwaves may require an automatic relay station at the point where the telegraph poles disappear out of sight in the illustration. Locating such a station on the hillside should give very great ranges.

Train-to-Train. Train-to-train communication, as in the illustration, offers little difficulty for either induction or space radio communication systems. Wayside wires are plentiful; multiple trackage exists; there are no curves; terrain is level; and there are no important physical barriers for a considerable distance. All these conditions result in good communication. Performance will be satisfactory on medium, very high, or microwave frequencies.

Humpyard or Classification Yard. The humpyard or classification yard presents a simple and dependable situation which has sustained tests of railroad radiotelephony as far back as 1940-1941. Any form of radio communication should be satisfactory on locomotives and cabooses in any manner of combination.

OPEN COUNTRY
Illinois Central merchandise freight train. (Courtesy Illinois Central System)

Induction radio systems should have a wayside wire available and extending along the middle of the yard, unless other wires are available to facilitate inductive pickup on mobile units. Low-frequency rail-carrier type of induction systems might need every third rail bonded.

Medium-frequency systems will work dependably at all times, since the air-line coverages involved are very small and the terrain is largely unobstructed.

Very high frequency, either AM or FM, will provide dependable coverage with minimum power and provision. Sets may be oversquelched to remove completely any trace of noise or electrical interference and will still provide satisfactory coverage.

Microwave systems will also give excellent coverage without the use of automatic relaying, booster, or reflection provisions. To cover all parts of the yard, the antenna need not be designed to produce a beam width greater than the angle of coverage required. A 12-inch parabolic reflector on the tower, in the foreground of the illustration, with a 20-degree beam width should cover the entire yard satisfactorily.

The existence of such a large amount of trackage, even when unbonded, is definitely a communication aid though not required to assist space radio because of the unobstructed line-of-sight conditions. The bridgeway crossing the railroad trackage should not hinder communication for any of the rolling stock in any position in its vicinity because

THE WAYSIDE SIDING
On the Santa Fe a remotely controlled power-operated switch at one of the sidings. (Courtesy Atchison, Topeka, and Santa Fe Railway.)

of the small amount of obstruction it presents with respect to the rest of the area.

Open Country. No communication problem is anticipated in open country, which is typical of much of the midwest. The land is level; horizon is unobstructed for many miles; wayside wires are plentiful; and multiple tracks exist. In this particular illustration, ground conductivity is very good as evidenced by the presence of moisture. Conditions such as these provide satisfactory communication for induction or space radio systems at any frequency.

Wayside Siding. The condition at the wayside siding illustrated is favorable for use of any type of induction or space radio communication. Wayside wires exist; terrain is level and straight; trackage is continuous; and the terrain is unobstructed for great distance in both directions. The power line to the right in the illustration might conceivably cause some interference in AM receiving equipment if it handles high-tension current and the insulators leak. Noise should not manifest itself when FM is used.

Port Terminal. No problem should be encountered in providing any form of induction or space radio communication for such a localized application as a port terminal. Lowest-powered equipment is sufficient to

THE PORT TERMINAL
Port Covington Marine Terminal, Baltimore, Maryland. (Courtesy Western Maryland Railway.)

cover such small air-line distances. The presence of water in the port area is a great aid in obtaining greater range and signal strength. The steel in low building structures, trackage, and bridges forms an integrated ground system to improve ground conductivity. If an induction system is employed, at least one wire should be available in each trackage area.

Space radio communication, either AM or FM, will be satisfactory. In the case of AM, any likely high noise or interference levels can be squelched out in the receiver and still leave sufficient coverage.

If the central station transmitter and receiver is located atop the grain elevator, the communication range will be great enough to work with trains miles away, such as 25 to 50 miles in the case of FM, or even more.

The shielding effect of the grain elevator in the illustration may be noticeable if very high frequencies or microwaves are used for train-to-train communication when it intervenes between them; but it is very doubtful that it would be serious enough to prevent good communication because of the extended ground path offered by the tracks, reflecting media presented by wayside structures, and the water paths around.

Tower and Dispatcher. Localized radio communications via any form of induction or space radio system in the vicinity of the towers should be

THE TOWER AND DISPATCHER
Interior of an interlocking tower east of Buffalo, New York. (Courtesy Association of American Railroads.)

effective on any frequency. The tower does not ordinarily require beyond-horizon ranges. Communication between the tower and trains in the vicinity of the tower should be an added assurance of safety and efficiency where so much traffic is being handled and such an intricate switching system is necessary.

Modern Passenger Train. The modern passenger train usually provides better facilities for two-way communications equipment than does the freight train, because it is designed for passenger comfort, and therefore the equipment receives much less shock and vibration. The passenger train is already well equipped with electrical power facilities to take care of car lighting, air conditioning, electrical appliances, and other conveniences.

Radio communication is undoubtedly welcome and impressive to the traveling public, being important in building up or retaining passenger patronage. A single serious accident to a passenger train may be far costlier to the railroads than several serious freight-train accidents because of the attendant publicity, loss of prestige, and uneasiness of

THE MODERN PASSENGER TRAIN
The "City of San Francisco," diesel-electric streamliner of the Union Pacific Railroad. (Courtesy Union Pacific Railroad.)

potential passengers. The former involves irreplacable human lives, while the latter largely involves replacable rolling stock and freight.

The conditions involved are no more complicated and are usually simpler than those previously discussed. Microwaves may be preferred in order to provide many channels of communication for possible toll telephone service via the Bell Telephone System while traveling, as well as to furnish entertainment programs or handle telegrams while the train is in motion. Dual facilities involving induction communication for railroad operations and microwaves for passenger services, with one available to substitute for the other in the event of a mishap to either, may be justifiable on such an important train.

CHAPTER THIRTEEN

POLICE, FIRE, AND FORESTRY SERVICES

1 Protection of Life and Property

Two-way radio is the greatest and usually the most economical single aid in protecting lives and property that community, county, state, or federal organizations can provide. Two-way radio enables small organizations to operate with the same high efficiency usually attributed only to large organizations with costly setups. Typical accomplishments of two-way radio are the following:

1. Provides communication and intercommunication between small community groups as well as senior county, state, or intrastate groups.
2. Individual departments have access to the facilities of the senior organizations without having to lose their local identity or the personal contact and knowledge of local conditions which a small organization has.
3. Definitely minimizes or eliminates the competitive and isolationist tendencies that sometimes exist between adjacent communities, various departments, and overlapping enforcement or protective agencies of city, county, state, and federal government. Two-way radio brings such groups together, so that they co-operate with and supplement each other.
4. Enables busy administrative officials to be cognizant of whatever is taking place, by monitoring the radio communications.
5. Improves morale because employees know their individual work can be recognized, since a radio log is used to record communications. Officials can scrutinize this log as well as listen in on the system.
6. Gives confidence to personnel because they know important information can be checked back, if necessary, and no detail need be missed.
7. Permits an official to inform headquarters immediately if it becomes necessary for him to deviate from his routine tasks, and makes him available in an emergency.
8. Saves trips, which tie up personnel and vehicles, by ability to connect immediately with a person close to or passing a certain point.
9. Enables a skeleton force to operate with the efficiency of 25 per cent more personnel, as men can be quickly contacted and dispatched to cover any situation that arises.

10. Reduces paper work, communication expense, and red tape. Matters that would otherwise go unheeded or be subject to delay, approval, or expense are handled directly and instantaneously.

11. Saves taxpayers large sums directly and indirectly, because departments handle breaches of the law while the trails are hot, fight small fires instead of conflagrations, conserve equipment, and make the best use of personnel.

The cost or complexity of two-way radio has now ceased to be a deterrent factor. In most cases, public departments actually waste taxpayers' money by not having two-way radio facilities, or by relying on crude one-way systems or on systems which include the maintenance of vulnerable and costly wire facilities. There is wastage in automobile depreciation, gasoline consumption, tires, repairs, hiring of temporary employees, communication expenses, and costly prosecutions as the result of delays in chasing cold trails.

As a rule, the taxpayers do not provide radio facilities with the intention of reducing the budget. They are usually satisfied if the budget does not increase, since they realize their communities are growing in population or in property value and that new developments are constantly becoming available. They know that radio takes the pressure off public servants and thereby increases their efficiency. But a well-planned system always results in additional unexpected economies. And these economies can aid in improving the working conditions of personnel by wage increases, additional help if necessary, a day off a week, or annual vacations if none were given previously. The maintenance cost of radio facilities is usually a negligible sum per unit. These facts were debatable in the minds of older officials, but the use of two-way radio has conclusively proved that they are true. Many of the greatest boosters and adherents of this invaluable aid to mobile operations are officials who feared and even undermined early efforts to install radio facilities in their departments. The same conditions prevailed in the merchant marine and in the navy in the early days of wireless, except during periods of distress. Radio has accomplished the difficult task of furthering co-operation between governmental groups and departments.

Experience over a period of ten years has proved that maintenance cost per mobile station for parts and repairs will always average less than \$5 per month per vehicle regardless of the amount or severity of service. Most vehicles will not exceed \$2 per month. Some will even go for a year without any maintenance cost, not even a tube being required. The Cape Cod master station, serving some 40 fixed and mobile units twenty-four hours a day operated an entire year at a cost of \$6.54. In no case did the cost reach \$100 for any station (maximum in this case 1000 watts) per year for the Cape Cod or the Maine systems, in continuous service throughout the year.

One maintenance man can handle up to about 25 mobile and/or fixed stations located within a 100-mile area if transportation facilities are provided. There have been cases during wartime personnel shortages where one man has handled as many as 100 stations with surprisingly little temporary inoperation. It depends on the quality of the equipment, the qualifications of the personnel, nature of the highways, care patrolmen give their cars, routine servicing procedures, and the design of the equipment.

No radio system is complete or correctly planned unless it provides communication between:

1. Any fixed point and any mobile unit.
2. Any mobile unit and any fixed point.
3. Any mobile unit and any other mobile unit.
4. Any fixed point and any other fixed point.

From at least one central point in the system, there should be communication with other services and with adjacent communities that operate on a different frequency.

The system should function under all conditions of power failure, storm, or disaster, when normal wire telephone lines and electric lights fail; in fact, even when the antenna system is damaged and makeshift facilities are necessary. The mobile units have no difficulty in that regard, as the storage battery charged by the automobile engine makes them self-sufficient. The fixed stations can have emergency gas-driven power plants as part of their normal equipage or can utilize a mobile battery-operated equipment on the headquarters antenna. If headquarters station is completely inoperative or damaged, then a mobile station immediately outside headquarters should take over the communication load.

The Cape Cod radio system paid for itself in full the night of September 21, 1938, a year after it was organized, by providing the only communication on Cape Cod during the hurricane. For three days Cape Cod had no electrical power, but the radio system was never out of operation. Emergency power plants prior to that time were not considered necessary, so communication in every case had to be conducted with mobile units using storage batteries. On September 14, 1944, the second New England hurricane struck Cape Cod with even greater severity, wrecking the top half of a 200-foot tower in a windstorm exceeding 100 miles per hour at one station. The entire system functioned with all important fixed stations equipped with emergency power plants. The station with the wrecked tower was back on the air in five hours, several hours before dawn, using the remaining 80 feet of the tower with a mobile-type antenna atop it. The second time, radio communication was even

more essential because of the greater severity of the storm, but it takes only one such situation to repay the taxpayers the entire cost of a system.

Wherever all parties agree, simplex operation of radio facilities is recommended. This means that everyone is on the same frequency. It ties up only one channel, and everyone can intercommunicate on occasion.

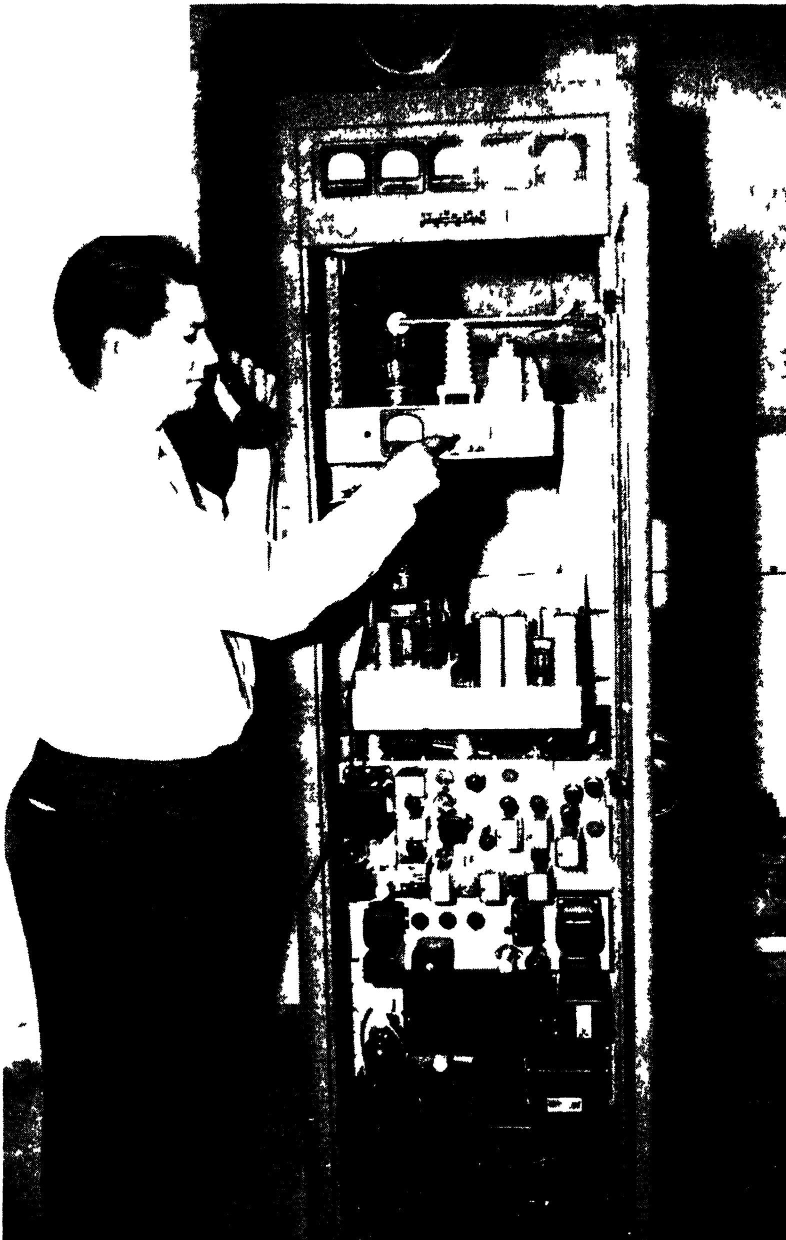
2 Police Department

A police department is often little more than a skeleton force. It is not uncommon for a community to have no more than one policeman for each 1000 to 2000 of the population. In the case of the state police, there may be less than one trooper for every 10,000 persons in the state. A federal organization may have less than one enforcement or investigation officer per 100,000 population. Nationwide senior organizations have a larger over-all personnel, but facilities are much weaker in any one area. Here and there a major city may have a local organization that is larger than the rest of the state police facilities, but it is mainly used for local traffic and ordinance matters.

Two-way radio communication becomes increasingly important as the ratio between police officers and population increases. A widespread state police organization is effective only if its personnel can be strategically and quickly moved from one point to another. When that can be done, it has the effect of a department several times the size, so long as major situations do not arise in many widely separated points at once.

Some communities, instead of basing their police force on the population, use property valuation as a basis. A year-round community finds population a primary basis. A vacation resort may find property valuation a more satisfactory basis, since much property is left unattended for the major portion of the year,and protection is expected in return for taxes. A frequent basis is to provide one patrolman for each million dollars of assessed valuation, although there are many cases where local police are in the ratio of one per $5,000,000 valuation. On the basis of a study of the requirements of fifty organizations, the police department for any community should consist of not less than one member for each thousand population, or not less than one for each million dollars of taxable property—the assessed valuation based on about 70 per cent of its replacement value. Whichever is larger should be the figure used. Such members should be exclusive of those required for civilian or desk work unless such additional personnel is also available for outside work. A community with a large population and low taxable valuation must expect higher police costs than a community with small population and high taxable valuation.

Except in the most prosperous cities, police are not exceptionally well



Experimental 116–120 megacycle two-way fixed radio station successfully tested by Chicago and Miami Police Departments and many others (Courtesy Galvin Manufacturing Co)

paid, and their working conditions may not be ideal. When an unusual situation arises, such as a strike, flood, disaster, or serious crime, they must work for continuous periods without rest or relief. Many departments do not provide for days off or even scheduled vacations for their personnel, who are subject to constant call night or day, the year round. Time off is possible only during lulls and then only by being subject to sudden recall. No police department, even with two-way radio, will be overmanned or be in a position to lay men off, despite the greater efficiency two-way radio makes possible. Instead, it permits handling the police load with less strain on the relatively small roster of qualified personnel.

For a cost of $200 to $500 per policeman, a police department can provide, paid for forever, the following legs of communication:

1. Police headquarters to police cars.
2. Police cars to police headquarters.
3. Police car to police car.
4. Police headquarters to substation.
5. Substation to police headquarters.
6. Substation to substation.
7. Men afoot using personalized units, such as walkie-talike or handie-talkie types.

If the same equipment is used by more than one man on a shift basis, the cost per patrolman can be halved or become a third of the figures mentioned. The small community not operating on a shift basis has a lower over-all cost but a higher per-man cost in providing radio facilities. The opposite is the case for a large city. The state police will have a much higher per-man cost because only part of their activities is on a shift ba and their coverage is so great that more power and special antenna locations are required.

The police department meets the cost of the radio equipment usually during the first full year of utilization by:

1. Keeping men out in the field and yet having them available at a moment's notice. The people and officials of a community soon notice that the police department is always on the job. The more the police are seen, the less lawlessness is likely to take place. The reverse can be expected if the department is too small or too immobile to make this possible.

2. Providing substantial police service coverage with a skeleton force.

3. Dispensing with the archaic method of keeping all officers patrolling on foot in rain, snow, sleet, or intense cold. It becomes feasible and economical to place them in patrol cars where they are able to cover much more territory than when afoot.

4. Dispensing with or reducing the dependence on crude signal or calling systems such as a light, a call box, the co-operation of a merchant on the beat, or a messenger to find the policeman.

5. Closing a road or bridgehead and preventing escape or entry of anyone in conflict with the law.

6. Forming a cordon over a considerable area and systematically closing in with good co-ordination to apprehend a criminal.

7. Assisting motorists on the highway.

8. Broadcasting alarms concerning robberies, stolen or abandoned cars, missing persons, and fire.

9. Summoning additional help in the event of foul play.

10. Communicating with personnel directly, calling in or diverting police officers, granting permission to change areas, or permitting police officers to leave cars when necessary without missing an urgent call.

11. Relaying information.

12. Co-operating with other agencies.

13. Providing communication in isolated areas, and during hours when other means are unavailable.

14. Co-ordinating movements of a parade.

15. Controlling major strikes or riots that are definitely beyond the capacity of the average police force, until reinforcements arrive from senior organizations. The available men and mobile units with two-way radio can at such a time be equal to several times their number without radio, because of better co-ordination and dispatch of information.

16. Providing communication between cars working on the same or similar tasks or relieving each other.

17. Reducing paper work and clerical routine.

18. Reducing car depreciation, gas, tires, mileage for a given amount of police protection.

19. Improving traffic control and clearing up bottlenecks and temporary traffic jams.

20. Summoning an ambulance or doctor in accidents.

21. Indicating the need for snow removal or for sanding streets or highways.

22. Answering calls to suppress rowdyism, assault and battery, and similar lawlessness, in time to apprehend the guilty.

23. Shadowing a person, vehicle, establishment, or area for a long period of time without exciting suspicion until major crimes are solved.

Police communications may be conducted by any of the following methods depending on local circumstances.

Headquarters to cars can be on medium frequency, such as the 1600-kilocycle band, in case the state police is on high power for covering the full limits of distance of a large state.

Headquarters to cars can be on very-high-frequency AM or FM on 30 to 40 megacycles, with FM preferable. This can be minimum power for local communities except in very congested business districts. For the state police, it should be equipment such as the 50 to 60 watts FM units using two 807 tubes or equivalent in the final amplifier stage of the transmitter. It will be more effective if efficiency can have its way over convenience and appearance by placing the antenna on the roof of the car in approximate center rather than on the side or rear shielded levels.

Cars to headquarters or other cars can be on very-high-frequency AM or FM, 30 to 40 megacycles. FM will be superior here also, since more output wattage can be developed for a given battery drain. If the car is not running with engine speeds sufficiently continuous and adequate to charge the storage battery an amount equal to its drain, it must be equipped with special oversize generators such as discussed in Chapter Three.

Cars to headquarters or other cars can use low-powered medium-frequency equipment where extreme ranges as well as very local ranges are needed. Skip ranges in between these two extremes can be tolerated by using other stations to relay or bridge such gaps.

Induction radio systems can be used in areas where wayside wires exist to guide the signals except for the small gap or lateral distance between the vehicles and the wayside wires at either end.

Walkie-talkie or handie-talkie units that are dry battery operated can be used by individuals. These weigh as little as 5 pounds complete and ready to operate.

3 Fire Department

Adequate communications by a fire department may mean the difference between fighting a small fire involving slight damage and expense or fighting a conflagration costing a community millions of dollars, which renders many homeless and destroys places of business and employment. Frequently lives and injuries are involved. Firemen are engaged in hazardous work and require every possible aid.

Radio in fire fighting is not an expense; it is a saving, financially, humanely, and materially. Two-way radio for fire departments is useful directly and indirectly in the following ways:

1. To dispatch fire apparatus to the scene of a fire.
2. To report to headquarters or any administrative point the extent of the fire and the progress being made in coping with it.
3. To summon additional help.
4. To obtain agreement about fighting a fire, particularly when it is being attacked in different ways with different facilities from points out of speaking or even visual distance.
5. To provide the only communication when men are cut off by fire or wreckage, thick smoke, noise, and commotion. A calm co-ordinator at such times prevents trouble by capable use of radio facilities.
6. To divert some of the equipment for a fire occurring elsewhere at the same time.
7. To co-ordinate activities with the police and local citizenry.
8. To summon help from other towns.
9. To summon or dispatch ambulances, doctors, nurses, or relief workers, or to arrange for hospital facilities.

10. To summon inhalator and resuscitation equipment with persons competent to use it.

11. To arrange for the relief, replacement, or nourishment of fire-fighting personnel when a fire is of long duration.

12. To control the movements and activities of fire boats.

13. To facilitate fire fighting on ships anchored in the harbor or even at sea.

14. To save man-labor hours in fighting fires or standing by.

15. To co-operate with other fire departments for an area of several miles in the event that any distressed community has a greater conflagration than its facilities can handle, also, in the event that equipment is laid up for repair or is otherwise unavailable.

16. To supplement the existing fire-alarm wire systems. Radio systems can be used by the public to turn in alarms.

17. To take over when fire puts out all other methods of communication and contact, including electric power.

18. To handle several small grass fires with the same piece of apparatus, once it has left the fire house.

19. To save time in getting water turned on and off and the pressure changed when a long fire hose must run around corners or up flights of stairs, or be similarly obscured from the source of water supply.

The fire toll in the nation is nearly a half billion dollars per year with a death toll exceeding 10,000 lives annually. There is much additional loss from major and minor injuries caused by large fires and also the small fires that individuals try to handle themselves without assistance. Discomfort and disruption of personal lives and business also causes indirect losses from fire.

The average fire department today consists of a fire house in which the apparatus is housed and where living and sleeping accommodations are provided for the firemen. Those on duty are largely unoccupied, except for routine maintenance tasks, when no fires occur. Two-way radio facilities make it possible for more firemen to engage in fire prevention work, a task for which they are exceptionally well qualified and which adds interest to their daily routine, and in inspections for violations of the fire laws and fire hazards. Time need not be lost in summoning them to a fire. They can proceed directly when called by siren as the location of the fire will be given to them over their car radios or units carried on their persons. Meanwhile the apparatus is taken to the fire by the skeleton force left in the fire house. Giving firemen opportunities to render varied services to the community without being confined to the fire house benefits them personally, as the prevention of fire and resultant decrease in fire losses influences insurance rates for everyone in such a wide-awake community. Not only should the number of large fires possibly be cut but also the time it takes for fire-fighting apparatus to reach the scene, when two-way radio becomes part of the equipment of a fire department. Fire losses and fire-fighting hazards are thus reduced.

Knowledge that there will be periodic inspections of premises by firemen causes prompt removal of inflammable waste and unsightly rubbish accumulations. It prevents other causes of fire that many persons do not realize exist, such as defective flues and wiring. Work of this type is always essential and worth while but cannot be extensively undertaken under the methods which prevail when a fire department operates without radio communication. In some cases, fire houses can be smaller, resulting in lower construction and maintenance costs, if a large force need not be housed on the premises in addition to the fire equipment. Even in the case of large paid departments, the number of firemen on duty in fire houses is not always adequate to handle all situations. Two-way radio communication is therefore important in all types of cases to maintain a force of extra men throughout a community or city who need not be on full-time duty.

In the case of volunteer fire departments whose members are scattered throughout the community, two-way radio performs miracles in calling them to fires promptly. The radio facilities can also be used by members to initiate fire-fighting methods among themselves. To call volunteers by telephone except with special provisions or in small-scale situations is time consuming and only partially feasible. Hearing the fire siren is dependent on whether windows are shut in winter, whether wind is blowing in right direction, and whether the man sleeps lightly or soundly.

In rural areas, two-way radio aids materially in using several pieces of lighter and less expensive fire equipment rather than one large piece costing as much as $15,000. Because of its size and cost, such a piece is usually required to cover a large area, and fires gain much headway before arrival of the equipment. If more than one fire occurs at the same time, there is excessive loss while one of the fires is being substantially curbed. Expensive equipment is often retained too long after it has become obsolete.

Equipment to furnish two-way radio communication for fire departments is largely identical to that used by local police departments. In addition to space radio systems, it is feasible to provide guided carrier systems over existing power or other wire circuits between fire houses and members of the department for call and communication when they are not outdoors or in mobile vehicles. The Halstead Traffic Communications Corporation has studied this matter with members of the International Municipal Signal Organization.

The following vehicles and agencies of the fire department should be equipped with radio facilities:

1. Hook and ladder trucks.
2. Pumpers.

3. Chemical trucks.
4. Hose trucks.
5. Utility trucks.
6. Fire chief and other official cars.
7. Fire boats.
8. Firemen on fire prevention duty or at scene of fire with self-contained portable walkie-talkie or handie-talkie units.
9. Substations.
10. Fire headquarters.
11. Homes or places of employment of volunteer members.
12. Rescue vehicles and ambulances.
13. Relief agencies and similar co-operating departments and officials in the community.

4 Sheriff Department

The sheriff department is a county organization, and there are more than 3000 counties in the United States. In some areas the work of the department is supplemented by local constables or marshals. The department may comprise a county jail and be the principal law enforcement group in rural areas where organized police departments do not exist. It also performs certain civil and court tasks in communities that have police departments. On occasion it works with all other law enforcement bodies. Much of its effectiveness is due to the natural aptitude of the personnel.

To communicate countywide involves average air-line distances of 25 to 50 miles usually. Such ranges are well within the coverage possible on very-high-frequency FM two-way equipment, and also medium-frequency AM equipment. The requirements of such a department can be largely met by induction radio equipment since wayside wires or other guided paths for carrier transmission usually exist in the areas of operation.

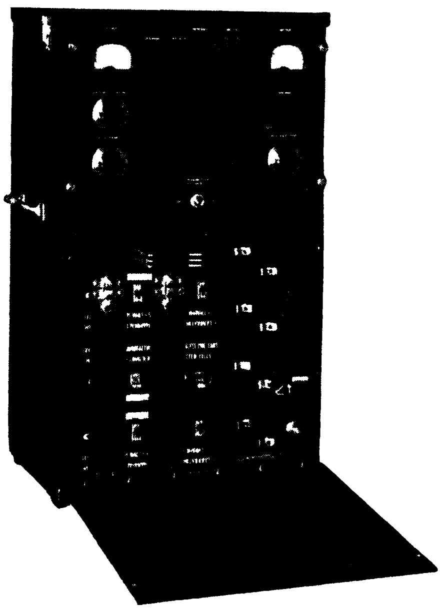
For the high sheriff of the county to reach all his deputies by mail or telephone is too slow and individualized a process. Two-way radio provides a quick, inexpensive, and unlimited means of contact. Frequently, deputies equip their own vehicles, as they can then receive immediate notice of fee-paying assignments, when they are on a fee basis, and also render quicker and better service to the county. Deputy sheriffs are usually an excellent source of information concerning local individuals and activities. Their practical or even intuitive methods, although unorthodox, often result in the solving of crimes when more scientific methods of elaborate organizations have failed. Although sheriff departments are gradually being absorbed into local and state police departments, many still function and their disappearance is not anticipated.

5 Forestry Services

Forestry services are responsible for millions of acres of undeveloped land, a vital natural resource of the nation. A single state may comprise

over ten million acres of timberland that require safeguarding. These vast wild regions offer great attractions to vacationists, hunters, and fishermen, and are placed under the supervision of fish and game commissions, recreation, park, and similar departments. Often the only persons residing in these largely inaccessible areas are employees of the forest department of the state. Unless additional men and fire-fighting facilities are promptly available, fires in such regions are disastrous.

Two-way radio in forestry conservation departments is used for the following purposes:



Special forestry two-way radio station for use in forestry towers and elsewhere, with long-life, heavy-duty dry battery power. (Courtesy Harvey Radio, Harvey-Wells Communications, Inc.)

1. To communicate between administrative center and fire towers as principal firsthand contact.
2. To exchange fire-fighting information between fire towers as to methods when actually fighting forest fires.
3. To check on smoke or questionable activities seen from towers.
4. To keep in contact with roving forest wardens who may be in camp, on lakes or streams, on horseback, in a mobile vehicle, or on snowshoes.
5. To send or to answer calls for medical assistance or advice and for food or other supplies.
6. To exchange weather information.
7. To circumvent areas that are obscured by fog, mist, or smoke by providing communication from a point in back or to one side of such areas.
8. To communicate between forestry planes, boats, towers, individuals, and administrative points as occasion may require.

Fire towers are located at vantage points but usually have no electric power. They have great horizons adequate for communication requirements. The logical power for them to use where no ordinary electric power exists is a wind-driven generator charging a storage battery. Also dry-battery walkie-talkie equipment with batteries replaced at intervals.

Microwaves are very suitable for tower-to-tower communication.

Very-high-frequency AM or FM equipment functions very well even with minimum power. The interference levels on such frequencies are usually nil in areas remote from man-made static.

Medium-frequency equipment will also function even on very low

power, but is subject to atmospheric interference from lightning and natural static, particularly during summer when most likely to be needed.

Induction radio facilities ordinarily are not suitable because of the scarcity of wayside wires.

Equipment should be light and compact and draw minimum power for operation. It has to be of a type that can be dismantled and conveniently carried or removed each season. It should be sufficiently simple so that the forest warden can make minor repairs or replacements, since he will frequently be too isolated for a routine service man to call.

A walkie-talkie dry-battery portable unit should be provided for use in the event that the regular equipment fails. At times it can be used for personalized applications in the area.

Provisions should be made to overhaul and store the equipment during the winter when forestry towers are not manned, so that the apparatus will not corrode or become damaged to the extent that it will be unfit for service in the subsequent season. Dry batteries should be removed; otherwise, they corrode or "cheese up" due to chemical disintegration after extended periods of nonuse, particularly if partially or totally discharged. Storage batteries should be used or cycled (that is, be given full normal charges and discharges) periodically when not in normal use.

When wind-generating equipment is used on the tower, it will supply extra current for minor uses. Since high winds may occur, exceeding the 70 miles an hour for which the equipment is designed, dependable governor-controlling features should be included so that the correct angle of tilt will be maintained. The propeller must not develop excessive rotating speed.

In lieu of wind-generating equipment, it may be possible to provide a small gas-driven generator and storage battery if it is feasible to bring in fuel. In some cases a miniature hydroelectric project, or a steam turbine arrangement of small size using wood for fuel may be possible.

If problems of providing power cannot be satisfactorily solved, intermittent use of the equipment on very brief schedules may be necessary for some locations. Equipment at such points is kept turned off, being turned on to transmit a message. It can be turned on to receive a message if a searchlight or other means is used to attract attention at unscheduled times. A compromise is to keep the receiver on continuously but the transmitter tubes completely off—that is, cold during standby with no transmitting tube filament power being consumed—and have no pilot or indicating lights on the equipment in order to conserve power. The extremely low power necessary in view of the high elevations and vantage points in forestry service makes it possible to use dry battery sets of a portable type capable of operating several weeks without battery replace-

ment. Good communication, even if below the maximum otherwise possible, can still be maintained for a period, such as a few days, after the batteries have started to become discharged, due to the low power and percentage of efficiency required to work under such favorable horizon conditions.

6 Public Works Department

Equally as important is the public works department of a community. It is sometimes known by other names, but its duties cover much of the following:

1. Street and highway building and repair, cleaning, flushing, sanding, and snow removal.
2. Electric light and power.
3. Water supply.
4. Gas supply.
5. Sewers and sewage disposal systems.
6. Building inspection.
7. City ordinance inspections of various kinds.
8. Miscellaneous activities of comparable nature either municipally or privately operated.

In all the above-mentioned services, two-way radio can be used to dispatch vehicles for both routine and emergency duties. The operation of several pieces of equipment can be co-ordinated by maintaining radio communication between the administrative center and the vehicles. As public works vehicles are usually large, costly, and cumbersome, reporting breakdowns by radio to make arrangements for towage and repairs will save hours in getting the vehicles back to work.

Traveling inspectors and officials can report by radio on situations that should be corrected immediately.

Radio can assist in maintaining communication contact when streets or highways are torn up, so that only one line of traffic can pass. Much confusion can be avoided by using radio to supplement or replace the red flag that the last car carries to show that traffic may start in the other direction.

The radio equipment required for vehicles costs less than 10 per cent of the cost of the vehicle. It will be usable again in replacement vehicles for a period of about ten years, allowing for normal radio obsolescence. It may be of the identical type used by the local police or fire department, in fact, may be on the same frequency, thereby increasing interdepartmental co-operation to the benefit and saving of the taxpayers.

7 Federal Law Enforcement

The enforcement of laws and regulations beyond the confines of a state becomes the responsibility of the federal government. For this purpose

there are many groups of small highly trained agencies which are shifted from one area to another to perform work that would otherwise require organizations many times their size. Their activities include the following:

1. Checking illegal radio stations and operations, by the Federal Communications Commission.
2. Checking bootlegging and alcohol tax evasions, by the Alcohol Tax Unit.
3. Checking tampering with the mail and using the mail to defraud, by postal inspectors.
4. Checking counterfeiting rings, by the Treasury Department or the U.S. Secret Service.
5. Guarding prominent national or international personages.
6. Guarding the borders of the United States against illegal entry, by the U.S. Immigration Service.
7. Guarding against smuggling, by the U.S. Customs Service.
8. Investigating crimes and sabotage or un-American activities, by the Federal Bureau of Investigation.
9. Protection during strikes, uprisings, or disasters, by the militia or the army.

The widely dispersed areas which the federal agencies must cover involve unusual communication requirements. In addition to conventional methods mentioned in this chapter, they may require long-range mobile and fixed communications extending across several states.

To accomplish this, very-high-frequency equipment is used for local operations and medium- or high-frequency equipment of special design for long-range operations. The latter largely depends on taking maximum advantage of sky-wave and skip communications. By carefully choosing the right channel or frequency band for different times of the day or night and for different skip range, amazing distances can be covered to virtually any point on the American borders, fixed or mobile. This equipment requires personnel acquainted with the behavior of the various portions of the radio-frequency spectrum, so that it can be made to provide the communication ranges required at any particular time. Specific equipment of this type is discussed in Chapter Twenty.

CHAPTER FOURTEEN

HIGHWAY AND PUBLIC TRANSPORTATION

1 Discussion

It is becoming increasingly uneconomical and competitively disadvantageous for public carriers of any kind to operate without two-way communication. This communication should be of a type that will function whether the vehicle is in motion, is stationary, or is even broken down. Connections with both fixed and mobile units of the same organizations should be possible at all times.

Frequently these facilities do not exceed in cost the economies which result from the first full year of utilization, because a vehicle can report its progress or predicament without regard to time, weather, or location and the fixed or administrative point can change instructions at any place or time to use its rolling stock to the best advantage. Fire, collision, breakdown, blocked traffic, derailment or skidding, serious tire trouble, crime, disorder, or suspicious circumstances, all are situations where radio communication would be helpful.

As two-way radio communication involves little or no extra cost for maximum use as compared to minimum use once a system is established, all organizational communication can be handled by radio. This eliminates the necessity of attempting to decide whether certain information should be handled by radio or by previously used means of communication. A bit of information which may seem unimportant at one moment may turn out to have been information that would have prevented an accident.

While licensing and regulatory requirements of the Federal Communications Commission with respect to two-way radio operations must be complied with, the Commission is always willing to receive applications that indicate a legitimate need for such facilities. The more recent developments on frequencies exceeding 100 megacycles plus new induction

radio techniques is enabling the FCC to consider applications that prewar it could not entertain. The time fast draws near when any person, firm, or organization can provide two-way radio for the protection of life and property, as well as to conduct business more efficiently, so long as the motives are legitimate. Nothing need prevent, financially or technically, this valuable aid of two-way radio from being available to any user.

Nothing said in favor of two-way radio should be construed to imply that dependence on the excellent communication facilities of the Bell Telephone System can be reduced. Instead, it is expected that the telephone system will undertake supplying certain radio facilities. While very large transportation groups can provide most of their own dispatching and fixed station facilities, this is not the case for everyone. It is very desirable that toll-operating companies provide fixed station space or induction radio facilities on channels specifically allocated for that purpose. This will extend the advantages of two-way communication to even the small independent transport operator and the motoring public, so that they need only equip and maintain their mobile units.

To enable the radio industry to flourish and not be closed out by any single group operating under a franchise, users will have a much wider selection of mobile equipment and the advantages of competitive costs and developments if toll-operating service groups confine themselves to only fixed station toll facilities. This is the basis which prevails in the marine radiotelephone field today. It then becomes possible for every mobile station to be in contact with the forty million telephones owned or affiliated with the Bell Telephone System throughout the world, in home, office, garage, ship, and aircraft, and subsequent expansion in the mobile or personalized radio communication fields.

2 Intercity Bus

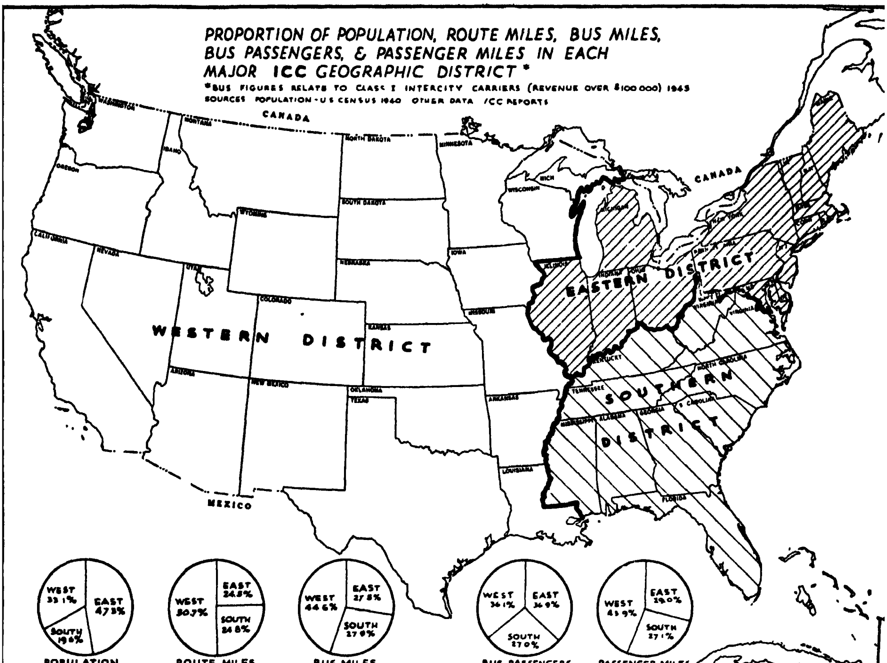
Approximately 25,000 busses are operated by more than 2500 bus companies in the United States alone. These vehicles operate in intercity service, covering more than a billion bus miles and carrying more than 500,000,000 passengers annually. Already the amount of route served exceeds 300,000 miles as compared with about 230,000 miles for all railroads in the United States. The dominant organization representing the bus field is the National Association of Motor Bus Operators.

The Greyhound Bus Lines is the largest organization in the field. The following figures are representative of its size:

Number of busses—4200.
Cost per bus—$22,500.
Capacity per bus—41 persons.
Service life—1,250,000 miles.

Number of garages—110.
Maintenance employees—approximately one per bus.
Crew per bus—one driver.

This vast fleet of busses operates through more than twenty subsidiary companies, each of which is responsible for service in several states, involving route mileages comparable with the longest individual railroads in the world. New postwar busses will carry more passengers, be double-decker type, and have toilet facilities. Additional features and



comforts are also contemplated, particularly as Interstate Commerce Commission and state regulations are liberalized and the postwar highway program becomes a reality.

There is little likelihood of any important increase in railroad mileage hereafter, even though the railroads may otherwise expand in the areas where they already possess right-of-ways. Instead, new expansion of transport will result from the social and economic developments in the United States and elsewhere, as rural areas grow into communities that will need to be served by bus and truck and in some cases by air. Busses and trucks provide comparable railroad functions without requiring exclusive right-of-ways. Only the helicopter type of plane shows possi-

bility of not requiring dependance on special airport facilities. The same paved intercommunity highways used for private motorcars serve as the right-of-way for the busses.

Bus transportation still has a long way to go to reach the peak of its development. The industry dates back to only about 1920 with much of its development having taken place during the last fifteen years. Even without the abnormal wartime travel increase, intercity bus lines have enjoyed a constant and substantial increase annually.

Much bus transportation is concentrated in the west and south in areas of sparse population where wire communication facilities are few and far between. Between terminals, the drivers of busses have no direct method by which they can communicate with fixed points or with other busses. The driver can communicate with his dispatcher by using a private telephone only when such facilities exist and are accessible, and permission to use them can be obtained. The driver must leave the bus unattended for a considerable time with resultant delays in schedule. In general, lack of radio communication results in unnecessary waste in the use of equipment and prevents the transmission of essential information which could prevent accidents or serious interruptions to the operation of bus vehicles.

On November 1, 1944, the Intercity Bus group in co-operation with the Radio Technical Planning Board presented their case before the FCC Postwar Frequency Allocation Hearings (FCC Docket 6651). It was one of the most intelligent and impressive cases ever submitted and will play an important part in making the universal use of two-way radio on busses a reality.

The four principal operating divisions of an intercity bus company in need of two-way radio communication facilities are: dispatching, safety, maintenance, and traffic. Dispatching requirements include the following:

1. To provide enough busses and driver personnel at the right place and at the proper time.
2. To handle passenger overloads at peak travel periods.
3. To provide relief equipment or drivers in case of accident, road failure, or other emergency.
4. To improve utilization of a bus not operating at capacity.
5. To keep the dispatching point advised as to the location of every bus at all times on the highway, and with respect to other busses in each direction.
6. In general, to dispatch a bus so that it may be started, stopped, speeded, slowed, diverted, put into service, or taken out of service as may be necessary.

Safety requirements include the following:

1. To exchange information as to weather, washouts, landslides, snow-blocked roads, forest or industrial fires, roads under repair, slippery conditions, or other situations unsatisfactory for travel,

2. To provide the most feasible and oftentimes only possible communication on open highways where the most serious even though not most numerous accidents occur.

3. To provide communication when no telephone exists or can be utilized due to location, hour, or wire prostration.

4. To facilitate the summoning of a doctor, nurse, or ambulance, or to arrange for hospitalization in the event a passenger becomes ill while traveling.

The maintenance records of the Greyhound system show a total of about 10,000 road failures per year for their 4200 busses. This means that on an average somewhere in the United States at least one bus per hour breaks down and urgently requires two-way radio communication. This represents one failure per 30,000 miles of bus operation or about 2½ failures per year per bus. At capacity load, it represents an inconvenience to approximately 400,000 passengers annually. This should not be regarded with alarm, as airplanes and railroads may at times inconvenience an even greater ratio of passengers due to mechanical failures, traffic volume, or weather. Radio, however, while not reducing the number of failures, can greatly reduce the delay in arranging for help and repairs and thus minimize the inconvenience to passengers.

Bus lines feel that the ideal method of reporting a failure is a three-way conversation between driver, garage foremen, and operating dispatcher. This permits providing for both the stranded passengers and the necessary repairs. Drivers have so many responsibilities that they cannot be expected to master a mechanic's job in addition, even though they do have considerable mechanical aptitude for most situations. According to the history of past cases, personal contact by radio would have solved many difficult situations. In several cases, costly equipment would not have been ruined by operation in a damaged condition. Even with the large number of garages maintained by a sizable organization, there are areas in the less populated parts of the United States where a bus can be several hundred miles from a desirable garage. An extreme case is between Fargo, North Dakota, and Butte, Montana, representing 1200 miles with no fully equipped and outfitted company garage in that area.

The traffic division requirements include the following:

1. To solve problems created by delays in arrival or departure of busses, including connections for passengers transferring from one bus line to another.

2. To arrange for service for passengers at eating and rest stops.

3. To arrange for extra busses when prospective passengers cannot be accommodated on the scheduled bus.

4. To determine whether a bus should interrupt its schedule to wait for a delayed bus.

5. To notify the terminal in advance concerning transfer passengers requiring connecting transportation, to ensure their receiving primary consideration.

6. To communicate orally concerning skip stops when making up a delayed schedule.

Two-way radio for bus lines also has the following miscellaneous uses:

1. To communicate between busses to determine the location of the nearest bus in an emergency.
2. To intercept or find a criminal or a missing person.
3. To arrange for help to quell a disturbance on a bus or to remove or subjugate an undesirable passenger.
4. To provide a means of transmitting an important message for an individual on the bus.
5. To maintain direct voice communication between originator and addressee with minimum third-party handling. Also to know immediately that a message has been transmitted and will be complied with.
6. To arrange for the transfer of a passenger from one bus to another on the open highway when necessary.
7. To provide communication facilities eventually for passengers and bus line personnel so that persons on the bus in motion or otherwise, regardless of location, can speak directly with their homes, offices, or other points by utilizing toll facilities of the Bell Telephone System or comparable communication network.
8. To serve as a valuable adjunct to the national defense by virtue of the existence of such a comprehensive nationwide communication network, functioning twenty-four hours a day. Taxicab radio systems can be a valuable supplement for municipal police; truck systems for state police; and bus radio systems for state police and federal law enforcement agencies.

Communication ranges required for busses are:

1. Communication inside the terminal.
2. Communication outside the terminal.
3. Communication for traveling distances of one hour.
4. Open-country communication for distances up to 500 miles.

To provide these various ranges on the same bus during a single trip, a combination of techniques and frequencies is necessary, involving both space radio and induction radio.

3 Intercity Motor Freight Carrier

About 600,000 large trucks and vans are associated with the national organization known as the American Trucking Associations, Inc. This does not include a much greater number of smaller trucks and delivery vehicles operating locally. These trucks are costly to purchase, license, operate, and maintain. They have a high rate of depreciation. Trucks are particularly important in areas not served by railroads. Elsewhere they are important because they can carry a capacity load per vehicle with a much smaller volume requirement, plus the fact that they operate door to door at shipping and delivery points. Competition requires that they work on a narrow margin of profit. This, in turn, can only exist with

Highway dispatching system using selective calling (Courtesy Halstead Traffic Communications Corp.)

efficient operation. A few serious accidents and a small trucking fleet may be in financial or operating difficulties. As the truck becomes older, it is increasingly subject to service failures or delays.

Much of the nation's farm and sea-food commodities, particularly where the distance is not more than an overnight trip to market, are hauled by trucks, operating at night when highways are deserted and help is difficult to obtain in the event of an accident. These trucks are owned by relatively small organizations; frequently a fleet is little more than a co-operative group of individual truck owners.

Two-way radio in the trucking field can be used for the following purposes:

1. To enable the owner or dispatcher to know where his trucks are at all times and to determine how the schedule is being maintained.
2. To dispatch a truck under way or not yet in service to pick up, discharge, or transfer a load.
3. To call for skilled help, parts, or a spare tire for a disabled truck. Some trucking fleets require their drivers to do nothing more than drive the vehicle. If the driver must walk to the nearest telephone or hail a passing vehicle to relay word of his predicament, he often must wait several hours for help or parts to

arrive. The owner is confronted with overtime charges and loss of valuable truck time.

4. To exchange weather and highway information between vehicles and with dispatching point.

5. To enable a green driver to obtain advice in connection with travel directions, short cuts, mechanical troubles, and the like.

6. To communicate with another truck for the purpose of borrowing spare parts or getting help in making repairs.

7. To give the alarm if robbery such as highjacking is imminent, as this crime reaches alarming proportions at times in lonely sections of highways.

8. To enable a truck driver to indicate where and why he is stopping when necessary.

9. To enable a truck driver to notify his dispatcher or employer that funds are needed or a guaranty of payment for an unexpected expense.

10. To indicate the exact time of arrival so that labor will be arranged for with a minimum of standing by.

11. To get a driver to change his speed so that he will arrive at the terminal at a certain time.

12. To co-operate with police and law enforcement groups as a supplement of police radio systems.

The communication ranges required for trucks are not much different from those required by bus lines. The trucks do not have to adhere to as rigid scheduling as do the busses since they do not carry passengers. The equipment described for busses is suitable for trucks.

4 Highway Communication Package

The Freedman highway communication package, comprising multiple performances and facilities in a single mobile or fixed radio station, was developed in November, 1944, to meet the needs of the Greyhound Bus Lines. It has subsequently been modified or improved as a result of conferences with the Federal Communications Commission and radio manufacturers. It has also been discussed with the National Association of Motor Bus Operators and the American Trucking Associations, Inc.

The package is designed to reduce or eliminate dependence on specially provided relay stations, other than those necessary at terminal and dispatching points for normal operations of a bus or trucking fleet. It utilizes a combination of techniques and inventions belonging to several individuals and firms both in the space radio and induction radio fields. The principal features of this package are:

1. The equipment comprises the equivalent of 2½ complete radio transmitters and receivers.

2. It can at any moment transmit, or transmit and receive, or receive on two different frequencies and communication ranges.

3. It utilizes FM exclusively regardless of frequency except where the licensing authority fails to sanction same.

4. The package contains an independent VHF or microwave transmitter and receiver complete with power supply and antenna system. In addition, it also contains a combination transmitter and receiver able to function on medium-high-frequency space radio or low-frequency induction radio. The combination unit utilizes a common intermediate-frequency amplifier, common audio system, and common power supply. The power supply of the VHF or microwave unit can be switched interchangeably with the power supply of the combination medium-high/induction radio unit. The medium-high-frequency space radio and the induction radio operations cannot be conducted simultaneously, as they will not be required to operate in that manner. This tends to conserve space, power consumption, parts, and costs without adversely affecting the communication needs of the system.

5. There are provisions for selective calling, so that a particular station or group of stations can be called without attracting the attention of other stations on the same frequency, or requiring that they constantly monitor the frequency.

6. An optional constant-checking feature is provided to assure the vehicle driver that his equipment is operating normally to receive transmissions from the dispatching point.

7. The equipment operates with a maximum output power rating not exceeding 50 watts for any leg of communication, with possibility of using much less. Because FM is used, the equipment requires little in the way of modulation components, which is little more than half the power consumption of similar-powered amplitude modulation equipment generally used heretofore in the radio field.

8. The equipment contains excellent automatic volume-control provisions to take care of signal fluctuation as a vehicle moves along the highway.

9. It also contains squelch noise control, so that noise will not actuate the loudspeaker when no signal is being received that would ordinarily override it.

10. Excellent signal quality and intelligibility is provided by utilizing frequency modulation's advantages through the use of the most feasible deviation ratio.

11. There is minimum possible response to static, lightning, and undesired interference by a choice of frequencies, FM, and methods while maintaining maximum signal-to-noise ratios.

12. To offset the modest power ratings of the transmitter components, excellent design and installation of antenna and transmission-line components are used in the mobile station. This is superior to higher-powered transmitters with less efficient antenna systems.

13. Equipment for either 25 or 50 watts output power is identical, differing principally by the use of two final amplifier tubes instead of one. The power supply is ordinarily adequate for either load.

Frequency Requirements for the Highway Package. Very-high-frequency operations can be conducted between 100 and 150 megacycles with design provisions for modification between 30 and 300 megacycles to facilitate FCC frequency allocation. Alternate facilities utilizing the Fonda-Freedman tube technique may also be possible on microwaves for frequencies exceeding 300 megacycles.

Induction radio utilizes frequencies exceeding 100 kilocycles extending as high as the FCC may permit. While the induction field technique is

ordinarily more unfavorable as the frequency is increased, it is compensated for in better signal-to-noise ratio, more ideal FM deviation ratio, and more frequency spectrum to provide more channels and less interference to wire carrier circuits.

Medium high frequency preferably utilizes a night frequency between 2000 and 4000 kilocycles and a day frequency between 4000 and 6000 kilocycles. In the event that only a single frequency can be obtained initially, preference is for a frequency nearly midway between 2000 and 6000 kilocycles. As the frequency is increased, the signal-to-noise ratio usually becomes more favorable and the more remote or distant stations can be contacted. The use of FM permits operations to continue even if two or more signals break through on the same frequency, due to its characteristic of permitting the strongest signal to take control at the receiver. Medium-high-frequency operations are only used during emergencies when VHF or induction radio is unable to perform the task. At such times, it is not necessary that the vehicle contact a specific point directly, so long as it can contact some point from which emergency information can be passed along by radio or telephone.

To provide positive communication under all conditions including the inoperation of one of the units, each leg of communication has a second choice and usually a third choice.

Inside the Terminal. Communication may be principally or solely confined within the terminal by utilizing induction radio exclusively without radiating into space. Existing wire or wires or a special wire run for the purpose can be used simultaneously for any form of useful electrical circuit. The dispatcher can communicate with the bus or truck for short distances to various lanes or sectors. By breaking the continuity of the wire, communication can be further localized to a specific lane or area or even a part of such space. Second choice: VHF or microwaves. Third choice: Medium high frequency on emergency basis.

Outside the Terminal. First choice is VHF or microwaves. Second choice: Where wires permit or the distance is sufficiently close, direct communication through the induction loop on vehicle and terminal. Third choice: Medium high frequency on emergency basis only.

Metropolitan Communication. This is for approximately one hour or more traveling distance, such as 25 to 50 miles. First choice: VHF. Second choice: Induction radio if wayside wires exist at the vehicle's location, even though the wires go underground elsewhere. Third choice: Medium high frequency on emergency basis.

Open Country. For various distances up to 500 miles or more. First choice: Induction radio for distances of 50 to 200 miles if wire conditions are favorable. Second choice: VHF for about 50 miles. Third choice: Medium high frequency for extreme ranges during emergencies up to any distance required. Alternate between day and night frequencies if they are provided.

Vehicle to Vehicle. Various distances. First choice: VHF about 25 miles. Second choice: Induction radio if wire conditions are favorable. Third choice:

Emergency medium high frequency utilizing the ground wave for local ranges up to about 50 miles and skip operation for ranges from about 200 to 1000 miles.

Terminal to Terminal. As they may exist. First choice: Guided carrier or induction radio 50 to 200 miles. Second choice: VHF for 50 to 100 miles. Third choice: Medium high frequency on an emergency basis for the handling of traffic of immediate concern to mobile units. Good for any required distance direct or in some situations by interrelaying between fixed points with correct skip distances for maximum signal conditions.

5 Railway Express

The express business of the nation, except for local small-scale services, is handled by one principal company, namely the Railway Express Agency, Inc. This is a merger of many large old-time express companies established as far back as the days of the pony express—the Wells Fargo, American, Adams, and others. It is a co-operative enterprise owned 100 per cent by all the railroads in the nation in proportion to the amount of business they originally contributed to it.

About 97 per cent of all express traffic is accorded either pickup or local delivery or both services, although this is actually done at about 6000 of the 23,000 offices maintained.

The Railway Express Agency has furnished the following statistics:

Number of employees: 57,000 persons.
Individual shipments handled: About 165,000,000 annually.
Shipping charges received: About $255,000,000 annually.
Steam railroads: Operated over 195,424 miles.
Electric lines: Operated over 1,929 miles.
Ocean steamship lines: 2558 miles.
Coastwise steamship lines: 2882 miles.
Motor-carrier lines: 16,251 miles.
Ferry lines: 7 miles.
Aircraft lines: 48,239 miles.
Gas motor lines: 1203 miles.
Railway Express vehicles: Total, 16,691. Gasoline auto trucks, 14,938; electric auto trucks, 421; trailers, 1332.
Investment in vehicles including garages: $30,000,000.

Express service is valuable to merchants and manufacturers because it makes possible the maintenance of low stocks of merchandise, which assures quick turnover, since the merchant knows that he can replenish his stock quickly and frequently. It is also important in the transportation of foodstuffs and other perishable merchandise in less than carload lots.

Two-way radio communication can facilitate quick service for the shipper and save delivery and traveling time for the company by notifying drivers of orders received after they have started on their routes.

In some places this is accomplished by having the drivers telephone to the administrative office while on their routes. But two-way radio obviously is superior to this method, as drivers receive orders immediately, as soon as they come into the office. Radio communication is also useful for such as the following:

1. To avoid delays for shippers of up to twenty-four hours or possibly a week end if the truck has commenced its route and cannot be otherwise contacted for the remainder of the trip.
2. To determine the location of the trucks at all times.
3. To enable a truck to indicate a mechanical difficulty or breakdown.
4. To enable a truck to call for additional facilities if there is more express business on a route than was anticipated.
5. To have a truck divert a shipment from one address to another after it has been picked up.
6. To send a call for help if someone tries to intercept the truck or a holdup is suspected.
7. To communicate between vehicles, and between offices and vehicles on all legitimate matters.

The air-line distance involved in any community served by an express office is small, rarely exceeding 5 miles and frequently much less. A choice of facilities is available to cover such a small area with a minimum amount of power. Costs vary from $100 to $500 per vehicle depending on the type of facilities required.

6 Delivery and Pickup Routes

Two-way radio for delivery or pickup vehicles is a field second only to that of the passenger automobile. It is not only economical but in many cases will be found to be productive of new business for the following reasons:

1. Retailers can maintain live inventories and fresh merchandise, knowing that distributors or jobbers can dispatch vehicles quickly to replenish stocks. It is particularly useful where small retail merchants handle stock on a consignment basis or accept orders on the basis of samples.
2. Distributors or jobbers can operate with reduced inventories, have quick turnover, and increase their business volume and quality of service.
3. Manufacturers can expedite the production of raw materials into finished products which move fast into and out of the retail market. The business cycle is speeded up, so that capital investment accomplishes more in the way of production, sales, and employment.
4. The consumer can order, or can increase, change, or cancel an order for such products as dairy companies deliver daily, as telephone messages can be passed on to the deliveryman by radio en route. The same idea is applicable in other trades, such as emergency delivery of gasoline to a gas station by a truck in that vicinity.
5. Vehicles out on their delivery routes are as promptly available as if they had not yet left the administrative office.

Taxicab radio dispatching system Calls received from the public at the telephone switchboard are recorded on forms and turned over to the radio dispatcher, who sends out the taxicabs by radio The map shows the city layout for all streets and block numbering (Courtesy Galvin Manufacturing Co)

6. The waste time and motion of carrying partial delivery loads is eliminated, as the nearest delivery truck can be dispatched to calls in its vicinity.
7 Costly or limited mobile equipment can be conserved yet more effectively used.
8. The difference in cost between a cash-and-carry business and one which offers a delivery or pickup service is reduced, making the latter available to companies that would like to increase their business by adding this service.
9. The administrative office knows where the delivery vehicle is at all times.

All the businesses that could use two-way radio for communication with delivery and pickup vehicles cannot be enumerated here, but the following are typical: dairy products; ice, coal, or beverage distribution; groceries, bakeries, and other food stores; laundries and dry cleaners; fuel and gasoline companies; junk dealers; garbage collection; newspaper and magazine routes; electricians and plumbers; department, furniture, and similar stores; local package delivery companies; towing and wrecking companies; sales organizations to keep in contact with salesmen in the field; insurance companies for contacting their investigators; lumber companies; manufacturers who maintain service engineers in the field.

Equipment for the communication required may be of any of the types discussed in this book, usually the simplest and least expensive type because the local community coverage involves less than 5 miles air-line range.

In addition to its affect on business service and sales costs, the cost of the radio facilities is usually covered by the savings in gasoline, tires, depreciation, and communication expense otherwise necessary.

7 Taxicabs

Taxicab companies need not lose revenue because of empty cabs if they use two-way radio communication. There are always prospective passengers, but empty cabs and prospective passengers must be brought together. For example, persons in residential districts seldom have a chance of getting prompt taxicab service, even though the larger companies have telephone dispatching services. They must wait until cabs report in at their stands before new calls can be taken care of. Cabs in the vicinity of telephone calls could be immediately contacted by two-way radio, thus saving time and gasoline, and gaining paid-for mileage. Small independent cab owners, comprising a large number, do not have the benefit of telephone dispatching.

Too large a part of a taxicab's mileage, gasoline consumption, and tire usage is unpaid for by passenger fares as a result of cruising and empty return trips to authorized taxi stands, where drivers find it necessary to park. Actually, in a large city there is much business off the main thoroughfares where stands are located, but it is scattered and unpredictable. Radio can make this business known to the taxicab drivers, saving prospective passengers from walking several blocks and providing more passenger fares for the taxicabs.

Specifically, radio is useful for dispatching service in the following ways:

1. When a taxicab discharges a passenger, the driver notifies his dispatcher at some central point in the city. He stops right there or proceeds to some near-by area to await a call originating in that vicinity. In fact, the dispatcher may already know the location of the cab and have another call waiting by the time the passenger is discharged.
2. A telephone call to the taxicab dispatching point in the community will result in the dispatcher ordering the cab closest to that point to pick up the prospective passenger. This permits fast service, ordinarily less than three minutes and a minimum amount of cruising by the cab.
3. If the dispatcher finds that his taxicabs are not ideally or uniformly distributed while standing by for calls, he can instruct them to cruise toward certain areas, so that a cab will be available in any part of the city without having to make an extended trip to a prospective passenger's location.

4. If traffic lights and regulations, rotary circles, one-way streets, and the like, make circuitous travel necessary to reach near-by points, the dispatcher can disperse cabs so that they will be strategically located to answer calls.

5. When drivers pick up stray passengers, they can notify the dispatcher of their destination, so that they will be ready to answer a call near the point where the passenger will be discharged.

6. Taxicab drivers find it unprofitable and passengers find it expensive to undertake trips to the outskirts of a city where there appears to be little chance of having a return fare. Two-way radio increases the possibility of contacting a return fare. It is also possible that passengers at more than one point require a cab. If these fares are combined, the cost is reduced for each passenger, and no more than one cab is required for the trip.

7. If there is an unusual request for taxicab service that the dispatcher cannot meet, or if there are not enough cabs available for a large number of calls in a vicinity, the dispatcher can broadcast the calls so that drivers can take care of them if their passengers are willing.

8. When a taxicab driver wants to end his working period near his garage or home, the dispatcher can give him calls that will be in that direction, so that the trip need not be made without a fare.

9. If a taxicab breaks down, a relief taxi can be sent to the point promptly to pick up the passengers, and repair or towing assistance can be quickly dispatched.

10. Suspicious circumstances noted by taxicab drivers can be relayed to the proper authorities. Thus used, two-way radio communication in the taxicab service becomes an important adjunct to the police and fire departments.

11. Not only can drivers talk with the dispatcher, but they can also communicate with other cabs. This is particularly feasible in smaller cities or communities where channel congestion is minimum and the radio system can be used for secondary or even personal communication between drivers as well as for the primary purpose of dispatching.

Since a taxicab is self-contained so far as power and antenna facilities to operate radio equipment is concerned, a taxi fleet equipped with two-way radio is especially valuable in time of flood, fire, hurricane, tornado, or civil commotion. Taxicab fleets greatly exceed the maximum number of vehicles that the police and fire departments can muster. In addition, the drivers are expert and know their territories as a whole much better than anyone else in the community. By enrolling the radio-equipped taxicab and driver in auxiliary police or sheriff organizations to give them legal status, they can become an important factor in maintaining law and order with little cost to the community to supplement the police department. The status of a taxicab driver in the community will then be important, and desirable clean-cut intelligent young men will be attracted to the occupation.

In the past, taxicabs not operating from an efficient dispatching system have not always used legitimate methods of competition. They have crowded into congested areas where many have fought to make a living and have ignored the outlying districts. Two-way radio will permit taxi-

Two-way radio in taxicab (Courtesy Galvin Manufacturing Co.)

cabs to operate on a co-operative basis in co-ordinated systems where calls will be equitably distributed; passenger usage will increase, and high standards of service to the public can be maintained.

Induction radio systems may be used for taxicabs if overhead or wayside wires are available for induced carrier transmissions.

Very high frequencies or microwave radio systems are recommended otherwise. To assure complete coverage, simple unattended automatic relay stations should be provided. In lieu of that, wayside reflectors, operating on the principle of the reflecting mirror and beam of light, and combination communication booster-repeater units at all mobile and fixed points should be used in conjunction with frequency modulation. These can be mass produced at costs as low as $100 if the quantity is sufficient and the cost of making sales is not too high. Methods of pro-

duction determine at what point between $100 and $500 the cost per mobile unit will fall. Maintenance and parts per unit, including the services of a qualified technician, can be kept below $5 a month in most cases, even less if the technician's services need not be paid for. Actual parts and tubes will average not over $2 a month for a system, regardless of the amount of service the equipment receives.

8 Subway or Underground Communication

Subway trains or vehicles operating in tunnels or underground cannot have the same space radio performance that is possible for vehicles on or above the surface of the earth. The shielding effect of the earth is responsible for this. However, communication facilities are still possible with some modification or limitation.

The simplest communication is possible for subway trains, which ordinarily receive their primary power from the third rail, as this rail is equivalent to a direct wire connection from the subway train in motion to the powerhouse or any point en route. This makes possible the use of wired wireless or carrier current systems without dependence on wayside wires or space radio facilities. The continuity and cross section of the third rail is excellent, even though it is of a material which is not so ideal a conductor as copper. Such a system is completely independent of obstructions to the line of sight, grades or curves, as well as the shielded tunnel.

The rails, which of course are always present, definitely improve any form of induction or space radio communication by forming an improved or alternate path. If, in addition, there is even a single conducting wire already existing or installed specifically for this purpose, then induction radio equipment of the types described for railroads in Chapter Twelve and also in Chapter Nine are feasible. Since the over-all mileage involved is only a fraction of the mileage of the average railroad division, and since the lateral distance between a subway train and wires in the tunnel is closer than on highways, very little power will provide excellent communication over the desired distances.

Space radio is also possible, but it will be only partially satisfactory on frequencies lower than microwaves. On microwave frequencies it will be satisfactory if used with beamed or focused antennas supplemented by wayside reflectors and/or combination communication booster-repeater stations as described in the microwave and railroad chapters.

This would make possible the following uses for subway trains:

1. From any fixed point to the motorman on any subway train.
2. From any subway train to any fixed point.

3. From any subway train to any other subway train.
4. Communication between sections of the same train, whether continuous or parted, in motion or stationary.

Two-way communication in subway trains may not be indispensable, since subway systems are already highly developed and equipped with elaborate visual and block signals together with indicating control boards. However, it will do what now cannot be done; namely, permit direct conversation with a moving subway train or a disabled subway train anywhere underground to arrange quickly for assistance and service restoration in the event of fire, flood, derailment, collision, or breakdown.

Frequency modulation is specifically recommended in subway services because the noise levels there will otherwise be very high from electrical machinery, large traffic over the tracks, and constant stopping and starting at stations located close together, as well as from the elaborate switch and visual electrical systems. The interference will be almost entirely man-made with virtually none being picked up from the atmosphere as natural static.

9 Surface and Elevated Electric Transit

Communications for trolley cars, electric busses, and elevated railroads dependent for primary power on actual contact with a trolley wire or a power rail, common in many large communities and cities or in suburban services, are simple to provide. The road mileage of such systems involves short air-line distances, usually less than 10 miles. The presence of a continuous electrical connection, whether it be elevated, track-side, or buried, makes it easy to utilize capacity-coupled connection to the power circuit. This is fairly ideal and continuous and provides the desired communication for the full limits of the transit system.

In addition or in lieu thereof, space radio techniques on very high frequency will usually cover the entire municipal or suburban area of a transit system with little difficulty. Usually this will be possible without any relay or booster stations.

On microwaves it is also feasible, but requires the use of reflectors or making each communicating point also act as an automatic repeater-booster station as described in Chapter Eleven.

Induction radio would also be useful and effective, as it can utilize the wayside wires or the power lines even without direct connection thereto by inducing a carrier along the wires.

Two-way radio communication is of value when public carriers must share congested streets or roads with other forms of traffic, which are at times blocked because of open bridges, grade crossings, accidents, and emergency situations. Such conditions upset schedules and cause street-

cars and busses to pile up at some points and become too far apart at others, with the result that passengers either have too many partially empty conveyances available or long periods of waiting and then overcrowded facilities. Communication by two-way radio aids in the handling of passenger traffic and in the maintenance of schedules in the following ways:

1. The dispatcher knows the location of all cars and busses at all times.
2. When a section of the route is seriously blocked, the dispatcher can switch or reroute cars or busses before they are jammed in the blocked section.
3. The dispatcher can direct the skipping of stops until the schedule returns to normal.
4. Traffic jams can be reported by car or bus or traveling inspector so that the schedules of other vehicles can be rearranged to handle the passengers.
5. Breakdowns in the more isolated sections of the areas covered by car or bus can be reported immediately, and transport of passengers can be arranged.
6. If the route is blocked as a result of flood or snow, the required equipment can be summoned immediately.
7. If disorder arises among passengers on a car or bus, police assistance can be quietly summoned without conductor leaving the car or bus.

In the case of elevated transit systems, the communication problem is simple. Space radio will render very effective service with one unit usually able to cover the entire city even from mobile points, because such systems are in the open and have an excellent ground path by virtue of the rails and the structural steelwork.

CHAPTER FIFTEEN

MARINE APPLICATIONS

1 General Discussion

Marine applications are the oldest and one of the most important utilizations of radio, dating back to Marconi's experiments in 1898. Radio was then called wireless in the English language, and similarly designated in other languages.

The development of marine two-way radio communication is the story of the development of all radio and even electronics. Prior to World War I, such communication was conducted exclusively by telegraphy, using skilled personnel and special equipment. Early equipment comprised the spark or arc transmitter used in conjunction with a crystal or cruder type of receiver. Prior to the development of broadcasting, which suddenly reached major proportions in 1922, frequencies lower than 1000 kilocycles, such as 600 meters or 500 kilocycles, were used. The latter frequency is still used for distress calls and as a common calling frequency for merchant marine and naval vessels. Many of the radio profession acquired their initial training and experience in connection with marine applications of radio equipment.

World War I brought out the vacuum tube for general utilization. This made radiotelephone communication feasible by voice rather than by telegraphy. It became possible for small craft, such as fishing boats, yachts, tugs, and fire Boats, to have radio facilities which could be operated by the owner or crew without requiring special personnel.

Radiotelephone communication received great impetus when the American Telephone and Telegraph Company around 1935 set up coastal harbor radiotelephone stations that tied in with the Bell Telephone System. It became possible for any craft to communicate with any other craft as well as with any point in the United States or the world that was available by telephone.

Marine radiotelephone equipment is usually of low power. Complete equipments cost between $200 and $2000. The transmitting power may be anything between 5 and 100 watts. The marine set usually uses several channels, and it can be shifted from one to another merely by throwing

Model M-25, six-channel, 25-watt equipment. (Courtesy Harvey Radio Laboratory.)

a switch or turning a knob. Except in special cases, all craft share common frequencies. The shore stations have a clear channel for each one. For that reason, ships can get a channel assignment without difficulty, while the shore stations are limited in number and are carefully studied by the licensing authority before a license is granted.

The frequencies employed are in the 2000 to 3000 kilocycle band, corresponding to wave lengths of 100 to 150 meters. Amplitude modulation, at least up to the present time, is used exclusively because of limited frequency spectrum in that band. The behavior of such frequencies for two-way voice communication is such that local ground-wave communication is possible for 25 to 50 miles, and long-range sky-wave operation is possible for hundreds of miles at night. Sky waves can be used twenty-four hours a day for about 200 miles by day and up to 1000 miles or more at night in winter. Night ranges, static and interference congestion permitting, are not impossible or uncommon from points as far distant as Maine to Florida. This may be true even with minimum power. However, these sky waves have intermediate zones of poor or no communication, corresponding to the skip ranges noted on short waves. Since all ships share common frequencies, congestion frequently takes place, at which time the stations most ideally located for skip ranges or those having maximum power and efficiency jam out the other stations on the band.

Static, storm, and lightning frequently interfere with reception and intelligibility in long-range communication. This is most evident during the summer months, particularly in the tropics, occurring when a storm is coming up the coast even though hundreds of miles away. During winter months, such disturbances are minimum, but the increased communication range brings in undesired stations from great distances to produce additional interference on the common frequency. This condition is true principally on the ship-to-ship channel. The other channels are more or less clear when required by a ship.

Because of the frequency and the low power employed, marine equipment is designed to work some station or ship anytime anywhere. It cannot work a specific station or ship anytime from anywhere, only sometime from somewhere. In practice, boats and shore stations are sufficiently numerous and uniformly distributed geographically to make possible communication at all times. This serves the principal requirements of being able to summon help, receive warnings, and communicate with a toll shore station. A longer or shorter long-distance telephone connection inland can be used in case the wanted toll shore station cannot be worked.

There is no reason why very high frequency or microwave frequencies cannot be employed instead of these low frequencies in order to reduce or eliminate interference, congestion, and static, and also to make available the advantages of frequency modulation. This would confine communication to local consistent coverage without long-distance radio interference and the static and other interference associated with sky-wave communications. Boats can be equipped with both medium-frequency and ultra-high-frequency facilities. The latter could be used for clear-channel local communication, while the medium frequency could be reserved for long-range communication.

The toll service of marine radiotelephone applications is an indication of how telephone companies or other licensees can provide similar service for two-way radio-equipped trains, planes, automobiles, or personalized stations, so that telephone connections can be made with any part of the Bell Telephone System.

Marine radiotelephone equipment is particularly important to fishing boats. Available types are sufficiently inexpensive and simple to justify installation on the smallest boat having a power plant for propulsion and battery charging.

2 Marine Radiotelephone Channels

As it is expected that radiotelephone equipment will be operated by persons not trained in the profession, there are special provisions in the equipment to assure operations on the correct frequency. Always the

transmitter, and usually the receiver, employs special quartz crystals that prevent transmission or reception on any frequency except the one for which the crystal is ground. The crystal, usually made of quartz, has the inherent characteristic of converting an electrical effect into a mechanical effect; conversely, it can convert a mechanical variation into an electrical variation. The thickness of the crystal determines the frequency at which it will do this. The higher the frequency, the thinner the crystal has to be, until finally at about 15,000 kilocycles it becomes so thin that it is very fragile and cannot handle much power without fracturing. However, on the marine frequencies between 2000 and 3000 kilocycles, a quartz crystal is sufficiently thick to be rugged enough for the requirements of marine communication.

It is therefore common practice to use a quartz crystal for every transmitting and receiving frequency. By having the equipment preset at the factory, it is possible to change frequencies at will, merely by operating a multipositioned switch. Equipment can be purchased with virtually any number of crystal-controlled channels. Usually even the most inexpensive equipment has at least three channels. More elaborate equipment may have up to ten channels; on special order it can be provided with even more than ten channels. These channels are all preset at the time the equipment is installed and rarely require further attention.

A ship having three channels might use them as follows:

Channel 1. Ship-to-ship on 2738 kilocycles to talk with any other ship it hears or wants to contact.

Channel 2. Coast guard or distress frequency on 2670 kilocycles.

Channel 3. A coastal harbor station frequency for the toll station ordinarily used to communicate inland over the Bell Telephone System.

If a ship has more than three channels available, then it can have the additional channels preset for additional shore toll stations and for the alternate ship-to-ship channel of 2638 kilocycles. Where a ship is not already equipped with extra channels and moves out of the area of the shore station for which its crystals are designed, the crystals must be changed; the right pair (transmitting and receiving) for the station to be used in the new area must be substituted. In simple low-powered equipment, changing crystals is sufficient, but usually there will be reduced efficiency until the circuits are turned slightly. In more elaborate higher-powered equipment, the circuits will require a fairly simple retune of the transmitting and receiving components within the unit.

In any one channel, the transmission and the reception do not necessarily occur on the same frequency nor are both crystals identical in thickness. They can be designed to be on any frequency with respect to each other. For example, two ship-to-ship channels are authorized: 2738

kilocycles and 2638 kilocycles. One vessel could on occasion transmit on 2738 kilocycles and listen on 2638 kilocycles. The coast guard or distress frequency is always on the common frequency of 2670 kilocycles so that such distress calls get maximum interception.

In virtually every case, the shore station setup involves the use of two frequencies per channel. For example, WOU Boston, Massachusetts, listens for ships on 2110 kilocycles but answers them on 2506 kilocycles. The transmitting crystal is directly cut for 2110 kilocycles, but the receiver frequency crystal is cut for 2506 kilocycles plus or minus the receiver's intermediate frequency, since the superheterodyne type of reception is usually employed.

Stations can use noncrystal operation and thereby have variable-frequency-controlled transmitters and receivers. In naval work this is common practice. It requires having an excellent frequency meter and a skilled radio operator to supervise frequency changing and equipment readjustment. Some equipment available involves a compromise. The transmitter operates crystal-controlled while the receiver is continuously adjustable. In that way the receiver is available for broadcast and other reception. It then becomes necessary to retune the receiver every time communication is desired and to remember to come back to the correct spot. Even if a variable-tuned receiver is left undisturbed but shut off, it does not remain on the correct frequency setting when the set is turned on again from a cold condition. It will be off frequency until the receiver has attained a stable operating characteristic, which may require hours. Receivers can also drift, due to changes in power-supply voltage if not crystal-controlled. Crystal-controlled equipment also drifts in frequency, but so little that it may be ignored for normal communication, since the drift does not exceed the band width of the channel.

The telephone company and others have provided transmitting and receiving facilities on shore to furnish two-way telephone service to vessels operating within range of a particular station. These marine radio exchanges or stations are established at points along the Atlantic, Gulf, Pacific, Great Lakes, and Mississippi shores and are being extended outside the United States proper. Since these stations operate on different frequencies, it is necessary for the boat's radiotelephone equipment to be fitted with the channels of all the stations through which the owner might desire to place or receive calls. If the equipment does not have sufficient channels, then extra sets of crystals are carried for insertion in place of the crystals not used at the moment.

The marine radio exchanges provide service to vessels within reasonable range of each station. The stations are connected by land wire to a centrally located distant office where the telephone operators establish

connection between the landline telephone and the boat. For example, WOU Boston is located at Marshfield, Massachusetts, but is controlled by the marine operator at Boston.

The shore station uses much greater power than the ship station. Also it may have several remote receiving locations tied in by landline control to pick up the ships from several different spots many miles apart. This also gives it a great receiving advantage over the ship which compensates for the ship's reduced power as compared to the shore station. Static permitting, the shore station, WOU Marshfield, has been worked in all areas between Cape Cod and Eastport, Maine, by day without difficulty with equipments from 5 to 25 watts in power. At night the ranges are erratic, Marshfield might be in the skip area, but Norfolk might be ideal skip range. Marshfield could still be worked but with reduced signal strength and fading effects.

Communication has been easy between yachts spaced about 200 miles apart, such as from the harbor of Chatham, Massachusetts, to Boothbay Harbor, Maine. Ship-to-ship communication between Eastport or Lubec, Maine, and Bar Harbor, Maine, 100 miles away, has been easy to maintain. Only interference from other stations, using the same frequency at the same time, or bad static noise prevents such average communication performance. These particular yachts were 30 to 75 feet in length, built of wood. Larger craft with better antenna space or with all-metal hulls are capable of even better performance.

3 Channel Utilization on and Toll Accounting

Every station, regardless of type or frequency, that transmits into space is subject to licensing regulations. The licensing authority in the United States is the Federal Communications Commission, which assigns call letters and designates the frequencies to be used. These call lists and current regulations are obtainable from the Federal Communications Commission in Washington.

Legitimate voice communication between ships is free and unlimited except where a toll service is set up for the accommodation of passengers. Communication is also unlimited and free with the U. S. Coast Guard for legitimate reasons, such as when in distress or to request medical assistance or to receive storm warnings.

At the time the radiotelephone is installed on board a boat, the company operating the nearest marine exchange should be advised. The company will open a ship telephone service account for the boat and supply the owner with details concerning charges for the service.

Radiotelephone calls can be made about as easily with shipboard equipment as with land telephone equipment, with one possible excep-

tion. Unless special facilities are provided, the ship cannot receive and transmit at the same instant, because the transmitter blankets out the receiver during transmission in most cases. As both are located in the same unit, sometimes using the same power supply and the same antenna, it is not always feasible to make the transmitter and receiver operate independently and simultaneously. However, the ship station can interrupt the shore station at any time while receiving from the latter. This is possible because the shore station has its receiving and transmitting equipment sufficiently isolated from each other physically and in frequency to avoid interaction between the two. Some equipments use voice-controlled relays, so that when the conversation stops for more than a few seconds it automatically goes back to receive position and automatically goes back to transmission when the microphone is again energized by voice. Such provisions, while workable and actually used in some cases, are more susceptible to mishap and require very careful design and adjustment.

A common practice is for a person upon completing transmission to say "over." That means the other party can take over and talk. Occasionally radiotelegraph jargon is still used on radiotelephone circuits, particularly by amateurs and old-time radiotelegraph enthusiasts. Instead of "over," they say "K" The letter K in telegraphy (dah-dit-dah) means "go ahead" in any language of the world. Other international abbreviations that old-timers may use are QRM to indicate "interference"; QRN for "static"; QRT for "cease transmitting"; QRX to "stand by"; "mayday" (from the French *m'aider*) or SOS for distress or help.

In utilizing toll shore stations of the American Telephone and Telegraph Company or such others as may be set up on a toll basis, three charges make up the total toll.

Ship toll. The owner of the ship station equipment gets credited with this amount when accounts are settled on both incoming and outgoing calls. This might be $.50 for three minutes.

Shore station toll. This goes to the owner of the shore station and might be $1.00 for three minutes.

Connecting toll. This is the telephone company charge for the use of the long-distance line, and is comparable to the toll that would be paid for incoming or outgoing calls for the city associated with the shore station, according to the origin or the destination of each call.

For the person ashore, the charges appear on his regular telephone bill; the person on shipboard receives a statement from the telephone company owning the shore facilities. When such an agency as the Department of Sea and Shore Fisheries, at Boothbay Harbor, Maine, or various fishery and cannery firms own and operate both shore and ship facilities,

no tolls are involved. In remote localities or during emergencies, tolls are avoided if a ship in port acts in lieu of a shore station. A yacht in a harbor may handle communications with craft outside. In general, the practice of a ship station at the dock usurping the function of a toll shore station is frowned upon except during emergencies.

The use of the equipment depends on the type of communication to be conducted. The ship set is switched to the appropriate transmitting and receiving channels. The following are typical examples:

Ship to Shore. Assume that the yacht Nourmahal, call letters WQBT off Nantucket, wishes to speak to a person at 6719, New London, Connecticut. The yacht's logical stations are Boston WOU or New York WOX. The landline distance to New London from both points is about equal, but the yacht's location off Nantucket makes WOU a better radio signal. The yacht switches to WOU channel and on 2110 kilocycles transmits: "WQBT calling WOU," or "Nourmahal calling Boston marine operator." WOU answers on 2506 kilocycles: "Go ahead, Nourmahal." "WOU from WQBT, let me have New London, Connecticut, 6719 person-to-person call with Mr. Williams." "WOU to WQBT, stand by." The call is arranged between the Boston marine operator and New London. Then WOU will say: "Boston marine operator calling the Nourmahal, here is your party, go ahead." The call is then conducted. It is monitored by the marine operator who will disconnect it when completed or reconnect it if anything goes amiss Other stations and ships do not hear the call unless they switch into that frequency deliberately. Even then they hear only one side of the conversation, since it is necessary to monitor both 2110 and 2506 kilocycles.

Shore to Ship. Suppose someone in Chicago, Illinois, wishes to talk to the yacht Dormar whose exact location is unknown, other than its being south of Hatteras bound for the Bahama Islands area on a fishing trip. The Chicago long-distance telephone operator will put through a call to the Miami, Florida, marine operator. Station WDR at Miami will call the yacht Dormar. It may so happen that the yacht is not listening at the time and has no automatic ringing device; it might be off the air to conserve the battery; or everybody may be ashore. The originator of the call will be notified that the ship does not answer at present. The shore station will include the Dormar periodically in her traffic list or after weather or news broadcasts to which ships usually listen. If necessary, other stations up and down the coast may be instructed also to include her call in their traffic lists. Sometimes a near-by ship hears the call trying to be effected and will signal or contact the called ship or relay the communication, as ships at sea must help each other on occasion.

Ship to Ship. As all ships have to share common channels, the two

generally available cannot be clear channels. When congested, which is usually the case near densely populated areas and yacht clubs, the loudest signal for the distance and conditions involved has the best communication. The others either have poor communication or suffer the inconvenience of biding time until the air is clearer and the station with the most power and most interference gets off the air.

While direct ship-to-ship calls involve no tolls, it is sometimes preferable to call via a shore station and pay the toll involved. By doing so a clear channel is obtained: namely, that of the shore station transmitting and listening frequencies, which no one else can use during that time. Also, each point has the advantage of the superior transmitting and receiving facilities of the shore station, usually providing better communication.

For example, two ships, 25 miles apart, can talk directly without interference. But if one ship is 50 miles north of Norfolk and the other 50 miles south during heavy interference and congestion on 2738 or 2638 ship-to-ship frequencies, communication may be very difficult. It is then preferable for both ships to work each other through the Norfolk station even at the expense of the toll, which might be $1.00 for three minutes.

If a ship off western Florida in the Gulf of Mexico wants to talk to a ship 150 miles north of Seattle, Washington, the ship would call WFA Tampa marine operator on 2158 kilocycles and listen for WFA on 2550 kilocycles. The Tampa operator would place a long-distance call to the Seattle marine operator who would use station KOW. KOW would transmit on 2528 kilocycles and listen on 2126 kilocycles to the other ship. When contacted, the two ships would speak with each other directly. There would then be two shore station tolls plus the long-distance wire charge.

Area to Area. When a ship moves out of a shore station area, it should notify that station of its destination. For example, a ship traveling from Maine to Miami would be passing by Boston, New York, Philadelphia, Wilmington, Norfolk, and Charleston stations. This permits calls to be switched to the station that the ship is able to communicate with by virtue of its location or the crystals of its equipment.

Ship to Coast Guard. This feature should never be neglected by a ship with detached communication. It is conducted on 2670 kilocycles. The channel is kept clear for distress or emergency communication. Because of that, even very low-powered transmitters with poor signal quality and strength can be intercepted for great distances. The U. S. Coast Guard mans this channel continuously with excellent equipment and competent personnel. So efficient is this channel that SOS is never used; the coast guard call NCU is generally used instead.

In sending a message during distress, remember that the equipment

may stop functioning any moment as the boat gets low in the water and the power fails. Therefore, forget the formalities and get the essential words through first: NCU, SOS, mayday, or help; next the location. Then if there is time come back with details of identity, personnel, damage, nature of help required. All ships should get off the air and listen during that time to give distressed craft a clear channel, only coming in to assist in relaying.

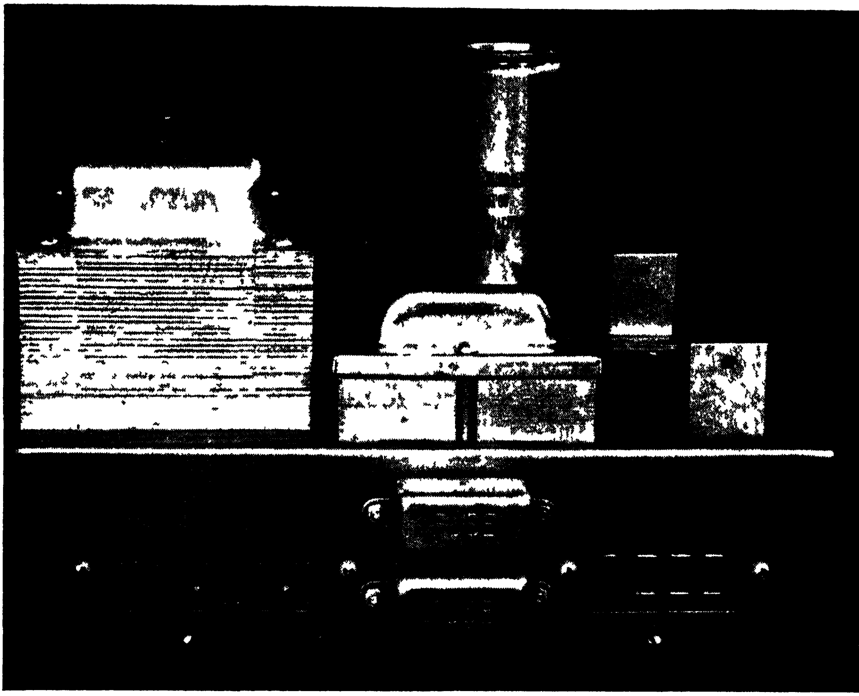
It helps the rescue vessel if the craft in distress can keep its signal on the air even without voice modulation. Hearing the signal on a radio direction-finder loop equipment facilitates steering in the direction of the ship in distress. The last thing a professional operator does in abandoning a merchant ship is to place a book on the key to make a continuous dash as long as the ship is afloat and there is power left to energize the transmitter. This helps other ships to get a fine triangulation fix on a chart by comparing bearings and thereby establish the distressed ship's location with great accuracy. It has not been uncommon for ships in distress to be as much as 100 miles out in their estimate of location, since they are usually drifting in distress during poor visibility Such a discrepancy means searching thousands of square miles of ocean aimlessly and delaying rescue operations at great expense and inconvenience to the rescuing craft

The coast guard can send a flying boat to pick up someone to rush to a hospital. Fishermen offshore 100 miles have been able to call on 2670 kilocycles for such help in cases of severe illness or injury. Within one hour the plane has arrived, picked up the man, and is headed back to the hospital ambulance waiting at the hangar. Medico messages are transmitted free of charge via the shore stations or the coast guard. A competent public health doctor advises by radio how to care for the sick or injured person.

4 Power of Marine Equipment

Marine radiotelephone sets can be energized by any power available. The more common types are 6, 12, 32, and 110 volts DC, and 110 volts 60-cycle AC. In some cases a converter is used to convert from an available voltage or current to another type. The size of the ship's transmitter is governed by two considerations: (1) the amount of available power on shipboard that can be spared to operate the radio equipment; and (2) the tastes and pocketbook of the owner.

As in the case of all two-way stations previously described, it takes more power to transmit than to receive, just how much more will depend on the rating of the transmitter. To a small extent, it depends also on whether the transmitter tubes shall be kept heated ready to operate



Dual-purpose power supply to function off either 32-volt DC storage battery or 110 volts 60-cycle single-phase AC by changing plug cable Manufactured for the Department of Sea and Shore Fisheries, State of Maine, and used with Harvey-Wells MR-25 (Courtesy Harvey-Wells Communications, Inc)

instantly during the receiving or standby condition On marine equipments where little transmission may occur, there is usually a switch to cut off the transmitter filaments and thereby conserve tube life as well as battery drain This explains why frequently no immediate reply is heard when calling a ship The ship will not be able to answer for thirty to sixty seconds until its tubes have heated sufficiently for proper thermionic emission. When the transmitter tubes are cut off and a call is heard requiring a reply, the delay in responding can be reduced if the tubes are turned on immediately ready for the reply. Sixty seconds may seem a short time but it is equivalent to the time that it takes to utter 200 words, and during an emergency seems like an eternity.

Longer run of wires, smaller diameter of wire or greater current requirement in amperes, all tend to produce an undesired voltage drop between the power source and the equipment. It is desirable to have the smallest possible voltage drop in transmitting power from a battery or other source to the equipment. There are three ways of accomplishing this, either singly or in combination:

1. Keep the wire run as short as possible between battery and equipment. The drop is uniform per unit length.

2. Use the largest-sized wire available and feasible to provide. Doubling the diameter of the wire reduces the voltage drop 4 times.

3. Use a higher voltage and correspondingly lower current in amperes to develop the same wattage. The voltage drop is equal to the resistance of the wire multiplied by the current flow in amperes. The resistance of the wire can be reduced by using a shorter length and/or using wire of greater diameter having less resistance per unit length. The amperage can be reduced without reducing the total wattage by using a higher voltage, since watts equal voltage times amperage.

As a boat is fairly small, the battery line is usually very short. The equipment is usually of low power, so that the amperage is fairly small. It is not too difficult to provide the above requirements for minimum voltage drop. To handle more amperage, use larger-sized wire. To handle greater voltage, use better insulation for the wire. Since the voltage used does not exceed 110 volts, the average insulation on any wire is usually sufficient.

POWER CONSUMPTION FOR HARVEY-WELLS MARINE EQUIPMENT ON SHIPBOARD OR COMPARABLE UTILIZATION

Ship Battery Voltage Volts DC	10-Watt Model MR-10 Receiver and Standby Amperes	10-Watt Model MR-10 Transmitter (While Talking) Amperes	25-watt Model MR-25 Receiver and Standby Amperes	25-watt Model MR-25 Transmitter (While Talking) Amperes
6	7	18	16	28
12	4	9	8	14
32	—	—	3	4
110	—	—	1	1

In computing the line drop, it must be remembered that there are two wires or the equivalent. A ground return in the case of a metal ship can be used, but that may not be less than the second wire.

MAXIMUM VOLTAGE DROP BASED ON TWO WIRES HAVING A 20-FOOT RUN

Size of Wire	Diameter of Wire in Inches	Ohms per Foot	MR-10 6 Volts	MR-10 12 Volts	MR-25 6 Volts	MR-25 12 Volts	MR-25 32 Volts	MR-25 110 Volts
B&S 2	.2576	.000159	.114	.057	.174	.087	.025	.006
B&S 4	2043	.000253	.18	.091	.283	.1416	.040	.010
B&S 6	.162	.000402	.289	.1447	.450	.225	.064	.016
B&S 8	.1285	.000640	.460	.230	.717	.358	.102	.025
B&S 10	.1019	.001018	.773	.336	1.140	.570	.163	.041
B&S 12	.0808	.001619	1.166	.583	1.813	.907	.259	.064
B&S 14	.06408	.002475	1.854	.927	2 864	1.43	.412	.103
B&S 16	.05082	.004094	2.947	1.473	4.585	2.29	.655	.163
B&S 18	.0403	.006510	4.6872	2.343	Total	3.645	1.041	.260

To compute the voltage drop, use the following formula:

Voltage drop = length of run in feet $\times$ 2 wires $\times$ amperage $\times$ resistance of wire per foot.

For example, if size-12 wire is used, compute the drop when the MR-25 is transmitting voice, load 28 amperes.

$$\begin{aligned}\text{Voltage drop} &= 20 \text{ feet} \times 2 \text{ wires} \times 28 \text{ amperes} \times .001619 \text{ ohm per foot} \\ &= 20 \times 2 \times 28 \times .001619 \\ &= 1.81328 \text{ volts drop.}\end{aligned}$$

Using a 6-volt battery, that would virtually leave only 4.18 volts when it reached the equipment. This would be inadequate to operate 6-volt equipment properly. The voltage drop should not exceed 10 per cent of the total voltage, preferably 5 per cent. If large wire is not available, the resistance of the run can be reduced by using two or more wires in parallel for each lead Two wires in parallel give a total resistance equal to half of one Three give a total resistance equal to a third of what one wire alone would give.

The maximum battery drain occurs only while actually transmitting. However, this drain governs the size of the battery wires to be used. In using a DC power source such as a battery, the correct polarity must be connected to the equipment. If it is opposite to what it should be, reverse the connections at the battery or at the vibrator or dynamotor.

5 Complete Installation

Marine radiotelephone equipment proper is self-contained and easy to install. It is the antenna, ground, and power supply connections that take time as well as require elimination or reduction of ignition noise.

The equipment may be mounted on a shelf or table or on the bulkhead. If convenient, it should be located as close to the antenna lead-in insulator as possible. It should also be located so as to have the shortest convenient run to the battery source in order to reduce the voltage drop. It should be ruggedly mounted to withstand the vibration of the engine and the severe rolling, wallowing, or pitching a boat undergoes in a very rough sea It should be bolted or screwed down with bolts or screws of sufficient size and bite. The location should be dry; if this is not possible, then the equipment must be protected against getting wet. The location should be remote from the engines to reduce the problem of suppressing ignition noise picked up in the radio receiver.

As the tubes generate heat when in operation, adequate ventilation and free circulation of air must be provided, particularly if the equipment is located in a locker or cabinet. There must also be sufficient space for removing the equipment cover to permit access to the chassis, to the meter tuning plugs, or other adjustment and tuning provisions. This varies with different equipments.

The entire setup comprises the following:

1. Antenna.
2. Lead-in from the antenna to the deck insulator.
3. Deck insulator which brings lead-in from the outside to the interior of the ship.
4. Lead-in from the inside of the feed through deck insulator to the equipment.
5. Equipment unit which usually is all contained within one cabinet.
6. Power cable from the equipment to the battery or other power source.

Usually the equipment is operated directly without remote control. Remote control or multiple control of the same equipment is possible from more than one point in the ship. It is not unusual to provide more than one loudspeaker working from the same equipment, so that incoming calls can be heard from more than one location. A common place of installation is where someone is always apt to be in attendance and where it is reasonably quiet. This is usually the wheelhouse of a boat.

As a boat rolls or pitches at sea, the signal may waver or vary in strength to some extent. This also may occur when spray or water wets the antenna, lead-in, or deck insulator. Water or spray causes some leakage to ground. Good selection of external components and their placement can prevent or minimize the reduction in communication efficiency which is the result of such conditions. What remains can be taken care of by the AVC (automatic volume control) incorporated in the receiving equipment of both the ship and shore stations. The AVC tends to increase or decrease electronically and automatically the amount of incoming signal applied to the grid of the vacuum tube by varying the bias as required to take care of the output variations of the tube. These automatic adjustments occur too fast for the listener's ear to detect.

The transmitter is adjusted slightly off the critical maximum peak, so that it will have more stability and not detune or go out of oscillation on a violent ship roll. A violent ship roll or bounce out of the water when under way at high speed might expose the ground plate or make the antenna whip and sway to change its electrical values. By adjusting the transmitter off the critical peak, it can continue to function during such times. In tuning the condenser in the equipment, it will be noted that as the condenser is turned in one direction from resonance, the signal falls off abruptly; when turned in the opposite direction, it falls off gradually. The condenser should be backed off from critical resonance point in the direction where it falls off gradually rather than abruptly. This will be indicated on the plate milliammeter. The same advice holds true for any radio equipment subject to vibration and motion.

The power cable running from the engine compartment to the equipment in the wheelhouse is subject to grease, moisture, and corrosive

Low-powered 4-channel (10-watt) marine radiotelephone Jefferson-Travis Model 101. (Courtesy Jefferson-Travis.)

action along its run for part of the distance. Good-quality rubber-covered cable can withstand this condition. Usually the voltage is very low, while the current is fairly high, particularly during transmission. As a result, the insulation is usually adequate for the voltage required, but the diameter of the wire itself may be too small, particularly if the run is very long. It should be of the largest convenient diameter with the shortest possible running length. More elaborate installations may use lead or armor-covered cable, stuffing tubes through bulkheads, junction boxes, and the like. These are not fully necessary for small installations.

Some equipments are designed to work on ship's voltage at sea and on 110-volt 60-cycle AC in port at the dock. The battery should be kept adequately charged, so that the equipment will always be ready to operate.

The receiver works from a loudspeaker or from the earpiece in the handset containing the microphone, or from both. The earpiece assures privacy when used alone.

6 Antenna and Ground on Shipboard

The performance of any radiotelephone equipment depends chiefly on a suitable antenna and ground system. This is particularly important where the transmitter is of limited power on shipboard. The height and length of the antenna basically control the range of the equipment. For efficient performance, the transmitter requires an antenna capable of being tuned to resonance at the operating frequencies of the equipment. Except in the case of large merchant and naval vessels, there is usually insufficient space to provide an antenna that is a quarter-wave or half-wave length long for frequencies of 2000 to 3000 kilocycles used in marine radiotelephone work. A full-wave length at such frequencies may be anywhere between 300 and 500 feet in length. Because of this great length, it is usually necessary to resort to artificial methods of increasing the antenna length. This consists of inductive loading, such as providing a coil of wire in series with the antenna. This coil may be within the equipment proper. It may comprise more than one coil in series. The amount of loading will change with each channel frequency. It will be least on the higher-frequency end of the band and greatest on the lower-frequency or longer-wave-length end of the band. This loading inductance does not radiate useful energy into space even though in the antenna circuit. Its only function is to permit the antenna to resonate or tune to the same frequency on which the transmitter is operating, so that there will be a satisfactory transfer of energy from the transmitter to the antenna for radiation into space. The inductance loading coil dissipates power, while the antenna radiates power. The ideal antenna system should have as much antenna

length as possible to radiate and as little loading inductance to dissipate and still permit the antenna to resonate at the transmitting frequency.

Antenna requirements for the receiver are not so critical as for the transmitter. Any antenna that is satisfactory for the transmitter is always satisfactory for the receiver. The receiver can make up for antenna deficiency because of the excess amplification, volume, and sensitivity it has available for use on occasion. The transmitter has no excess power to spare for inefficient performance.

It is possible to minimize power dissipation by locating an enclosed loading coil at the top of an antenna which otherwise might be inadequate in height or length, or in both. Top loading, while admittedly efficient, is not extensively used because of the physical difficulties in locating the coil atop the antenna. Improved mechanical and electrical design in the future may warrant greater use of this type of antenna for lower-frequency mobile operations.

Vertical antennas are preferable to horizontal antennas on small craft, as they are less directional. A 30-foot vertical antenna with a loading coil may be better for general communication than a 60-foot horizontal antenna on a low mast. A 30-foot vertical antenna may be no more than a simple bamboo pole, supporting insulated wire wound around the pole and held in place with tape. This may be varnished but should not be painted with a metallic paint that has shielding qualities. The wire ordinarily used is not smaller than B & S size 12.

If the transmitter tunes satisfactorily on lower frequencies and poorly on the higher frequencies, the antenna is too long. Inserting an insulator part way will reduce the antenna length, or use less loading inductance by shifting the inductance tap. If this is not possible, then insert a condenser in series with the antenna.

If the transmitter tunes satisfactorily on the higher frequencies but poorly on the lower frequencies, then the antenna is too short. Lengthen the antenna or increase the amount of loading inductance. The lead-in outside and inside the ship to the equipment adds to the antenna length. The ground connection to the equipment also adds to the effective antenna system length. Changing any of these will affect the resonant frequency of the antenna.

The antenna should have good insulation at its ends and where the lead-in comes down and goes through the deck. The insulators should have a long leakage path and be able to shed water readily. The antenna wire should be noncorrosive of either copper or phosphor bronze. The lead-in from antenna to equipment, being in series with the antenna, also radiates. This radiation is only partially effective because of the location of the lead-in with respect to the antenna.

An important and indispensable part of the antenna system is the radio ground. This ground is also useful for interference suppression. The better the ground, the greater the range will be. Salt water is an excellent ground and makes possible better radio ranges than can be obtained ashore. However, many of the boats having marine radiotelephone equipment are built of wood, and it is necessary to have a satisfactory ground which will make good contact with the water. The usual way is to provide a large flat metallic area under the water line to which the radiotelephone equipment is grounded. It must be so located that it will always be submerged sufficiently regardless of the vessel's roll or pitch in a heavy sea. This means placing it near the keel and not too near the bow or stern. Copper sheet is normally used; monel or sheet brass may be used. Cut copper boat nails are used to secure copper; screws are used for brass; monel nails or screws are used for monel. The nails or screws must be the same as the sheet metal in order to keep electrolysis to a minimum. Any weight of sheet metal may be used, as the amount of surface is the primary consideration. It may be square or rectangular. Sets up to 10 watts use 4 to 8 square feet of plate area. Up to 20 square feet can be advantageously used for sets up to 100 watts power. A bronze, monel, or brass bolt is soldered or brazed to the sheet metal and carried through a tight hole into the hull. Inside it is made up with a large washer and lock nuts. The ground lead from the set is then soldered or otherwise rigidly and electrically attached to the ground connection.

The ground lead wire should have very low resistance between the equipment and the ground. It is kept short and direct. To keep the grounded connection short, the ground plate or sheet should be located under the space where the radio-telephone equipment is located. Ground leads can be ½-inch tinned-copper shield braid tacked in place, or a strip of sheet copper ½ inch to ¾ inch wide. Copper tubing or ordinary battery cable may be used.

Do not use the engine or propulsion components of the boat for a radio ground. It is not a good ground electrically; it is not stable and constant and may introduce interference to the receiver. The engine has a long path to water with a high and variable resistance as the propeller shaft turns and the engine vibrates on its foundation. In some cases, the water cooling system with underwater piping makes a satisfactory ground. Once the ground is provided, its length to the equipment should not be changed, as that would throw the transmitter out of adjustment and require retuning.

7 Noise and Interference

Complete elimination of noise and interference on shipboard is not always possible when a ship is in motion or its power plant is in opera-

tion, particularly when the battery is undergoing charge. The use of frequency modulation would be very helpful, but FM is not used on marine frequencies, where the frequency spectrum is too limited. However, FM could be used by redesigning the equipment for this type of radio service.

Noise is more difficult to eliminate on wooden ships than on metal ships, a wooden ship being more difficult in this regard than the ordinary metal automobile. Each installation may encounter interference of a different type and amount. Remedies for common types of interference are given here:

1. Engine floating can be remedied by grounding the engine.
2. Interference from certain spaces can be remedied by shielding the spaces and grounding the shield.
3. Interference from the spark plugs of the engine can be remedied by attaching a spark suppressor on each spark plug. If the increased gas consumption and somewhat reduced power cannot be tolerated, then compromise by using one suppressor on the distributor only. Use inductive wire-wound suppressors to reduce gasoline and power loss.
4. Install a condenser to ground where primary wires enter the ignition coil of the engine.
5. Shield the high-tension wires going to the distributor of the magneto and ground the shield.
6. Screen the motor, but this helps only in some cases.
7. Separate high-tension from low-tension wires.
8. Filter the power-supply leads.
9. Filter the lighting wires in the compartment.
10. Replace all plain insulated wires with shielded wires having their shields connected to ground.
11. The generator is usually a source of noise. If condensers are used between hot side and ground, it is advisable to install a fuse in series to blow in the event that the condenser short-circuits.
12. The various motors and fans on a ship can introduce interference, particularly the DC commutator types having brush spark. Install a .5-to-1 microfarad condenser across the leads close to the motor.
13. Lining the underside of the engine hatches and the deck with fine-gauge copper mosquito screen, which in turn is grounded, may be helpful.
14. It is possible that circulating ground paths bring in interference. This can be remedied by changing the point at which anything is grounded, or by grounding at a certain point, or at both ends only, rather than at random points.

Very severe cases of interference should be analyzed by connecting a cathode-ray oscilloscope in the receiver output to study the wave-form distortion and observe the effect of various corrective measures.

8 High Frequencies for Small Vessels

Where small or even larger vessels desire channels free from interference and equipment that will use low battery power and may be taken

from the boat for use elsewhere, then equipment designed for very high frequency or microwaves offers many advantages. This is particularly feasible where communication ranges between a fraction of a mile and 50 miles is sufficient to meet all needs.

In many successful tests, equipment of less than one watt power has maintained communication for distances exceeding 50 miles on microwave frequencies, either with AM or FM. The high frequency and the exceptional ground conductivity of the water path provides better ranges, with greater uniformity and consistency for all ranges up to the threshold, than are encountered over land with variable terrain.

The range that can be obtained two-way depends largely on the height of the antennas of the transmitting and the receiving stations. As the frequency used is increased, power becomes less and less important, until at microwaves it can be minimum (that is, less than one watt) for the same amount of range. In the case of rowboats, sailboats, or craft not in motion, there is no electrical interference from the ignition system or rotational or propulsional equipment, so that maximum signal-to-noise ratios are possible.

In the case of normally operating and powered equipment the actual ranges will be not less than the visual horizon, and be as great as two to three times that horizon on frequencies approaching the microwave band utilizing FM. Where medium-frequency equipment is compelled to share common frequencies with all other craft, there is much interference. This will not be the case on the higher frequencies, as sufficient spectrum and the absence of long-range sky-wave reflections from erratic distances and undesired stations insure privacy and interference-free channel space. This makes it possible to use the equipment for less essential personal conversations in addition to emergency or distress communication.

The minimum ranges based on the maximum optical horizon are given below. (Double or even triple these ranges may be realized for radio communication, depending on frequency selection and equipment efficiency.)

Between	Optical Horizon Miles	Radio Ranges up to Miles
Person standing on beach with walkie-talkie or handie-talkie unit and rowboat offshore with antenna 4 feet high	5	15
Two small sailboats, each having an antenna atop the mast about 16 feet above water line	9.8	25
Two rowboats, each having an antenna 4 feet above water line	4.9	10–15
House on shore with antenna on roof 36 feet above water and sailboat with antenna 25 feet above water	13.5	25
Two large vessels at sea	25	75

To compute any other condition, compute the horizon of the transmitting point's antenna above sea or water level by using 1.225 times the square root of that height in feet. This will give the range in miles. Compute it similarly for the receiving point. Then add the two ranges together. This will give optical distance. Then multiply it by a constant determined from actual experience encountered with a specific type of equipment. For microwave equipment using beamed antennas and ultra high or super high frequencies, the constant may be 2. Less efficient equipment may be somewhat more than 1 or the actual distance that the eye could see if there were no fog, mist, or darkness. On lower frequencies, power must offset the reduction in frequency in order to maintain the same range or signal strength. Too low a frequency with too low a power can conceivably give useful communication ranges that would even be less than the distance the eye can see. This will not be the case on frequencies exceeding 30 megacycles, and the ranges on frequencies exceeding 300 megacycles will not even be approached.

Radio ranges will always exceed the best visual ranges on microwaves regardless of the amount of power employed. This has been definitely confirmed with a hundredth of a watt power on a frequency as high as 3000 megacycles. In another series of tests, using about 1800 megacycles and a tenth of a watt power, even with less efficient amplitude modulation instead of FM, ranges exceeding 70 miles were reported by competent radio personnel, using very modest equipment of miniature size.

9 Direction Finding

The same equipment when used on microwaves with a directional antenna, such as a simple parabolic reflector or multielement array, makes an excellent radio direction finder or homing device to guide a boat in case it gets lost in darkness or fog or does not know its location. For example, on 3000 megacycles, a parabolic reflector about 12 inches in diameter, that resembles the reflecting mirror in a locomotive headlight and can be held in the hand or mounted on the equipment, will hear the signal when aimed at the station and hear it weak or not at all when aimed in other directions. The same can be done also at shore points, if desired. Such a beam width would be 20 degrees wide. By swinging the reflector back and forth once or twice and noting where the signal falls off from a known transmitter, one can head for the direction halfway between the falling-off points and find the source of the signal with an accuracy of one or two degrees bearing. If the reflector is designated to operate with a pointer on a 360-degree circular scale, each point can determine what it bears relatively from that point's location. This will

give bearing but not distance. To get distance, the bearings from two or more points are laid out on a map, even a rough one, and then the distance and exact location of the triangulated station can be quickly and simply spotted. Even a nonmathematical person can learn in a few minutes how to utilize this information for navigational and safety purposes in addition to communication.

If a loop type of antenna is used for the receiving antenna, the receiver will work best when the loop is in the same plane as the transmitting source. It will be weakest when it is at right angles. By connecting the loop to a compass scale, relative bearings will be obtained. Knowing the identity of the signals picked up, two or more such bearings can establish the exact location by triangulation fix on a map. This may be used on any frequency, rather than on microwaves alone, as is the case when parabolic reflectors are employed.

Because certain types of antenna design have directional characteristics in the transmission or reception of radio signals, ships at sea and aircraft aloft are able to navigate with safety under even very adverse conditions. Not only is this possible with a high degree of accuracy, but radio bearings are relatively rapid and simple to obtain. In its simplest form, a radio receiver using a rotating loop type of antenna hears any radio signals within its receiving range weakest when the antenna is broadside to the direction from which the signal originates, and loudest when the loop is in line with the same. From that initial stage has come the radio beacon, the aviation radio beam, the naval radio compass station, and other navigational aids. These are of greatest importance during fog and conditions of poor visibility.

Medium-frequency direction finding is aided by the following radio bearing applications established by the United States. Foreign countries maintain similar services.

Naval Shore Radio Compass Stations. The land radio compass stations in the United States are owned and operated by the United States Navy, using enlisted personnel. These stations serve both merchant ships and naval vessels, performing this service gratis. They usually operate in groups located within 50 to 100 miles of each other. When a ship calls one station, it receives bearings of the various stations in the group.

The principal use of such stations is to tell a ship requesting such information what it bears in degrees from each of the stations in the group. Where any two bearings cross on the chart will be the ship's position. These stations also (1) enable ships that have direction finders to take reciprocal bearings and check the accuracy of their facilities; (2) serve the naval establishment afloat; and (3) serve aircraft able to operate on such frequencies.

These stations ordinarily send and receive on 800 meters or 375 kilocycles, maintaining twenty-four-hour service. The international Morse code is used for communications. They are located along the Atlantic, Pacific, Gulf, and Panama Canal coasts.

Radio Beacon Stations. At many lighthouses and aboard many lightships, the lighthouse service, now part of the U.S. Coast Guard, using enlisted personnel, operates radio beacon stations on about 1000 meters.

These stations are the equivalent of a lighthouse. Instead of a fixed or intermittent light, the radio beacon sends combinations of dots and dashes for certain intervals. For example, one lightship might send single dashes (dahs) for 60 seconds and pause 60 seconds, then resume for 60 seconds and pause again, repeating the process. Another might send dot-dash (dit-dahs) for 60 seconds and pause 90 seconds. By the combination used and the time intervals, mariner can identify the station heard even without knowledge of radiotelegraphy. Ships with radio direction-finder receivers can get bearings on such known locations and determine their positions accurately and rapidly.

Radio beacons operate at certain times of the day and night during fair weather. They also operate continuously during fog or poor visibility.

Radar. Essentially, radar consists of a radio transmitter sending out a series of spaced short pulses which may be of only a millionth of a second (microsecond) duration each. These individual pulses cause radio waves, traveling at 186,000 miles per second, to strike any mass or object and reflect back. The direction of the reflecting mass or target is determined by the direction the rotatable antenna faces. The distance of the reflecting mass or target is determined by the time it takes the signal to leave the transmitting antenna and return to the associated receiver. A cathode ray tube indicator is used instead of the common loudspeaker or earphones when the signal returns. This tube is calibrated directly in the simpler forms of radar. In the more elaborate models it operates in conjunction with a range-measuring unit having a counter that is read off. This makes possible the determination of range or distance of the reflecting body. It is done by measuring in microseconds the time that elapses from the moment the pulse started at source and return of the signal. It computes to 164 yards of distance for each millionth of a second of time which elapsed. Actually a radio wave travels 328 yards a microsecond, but in the case of radar it must travel out and back.

CHAPTER SIXTEEN

AERONAUTICAL APPLICATIONS

1 Discussion

Aviation and radio are about the same age and have made comparable progress. Both involve the shortest and most direct approach between two points. For new applications and in areas still largely undeveloped, they by-pass former methods of transportation and communication. Both are destined to make further progress and have many offshoots.

2 Uses of Aviation Radio

Radio has become indispensable to aviation, enabling planes to fly night and day, in good or bad weather, in any kind of visibility. The chief tasks that radio performs for aviation are:

1. Provides two-way communication with the earth.
2. Provides two-way communication with other aircraft.
3. Guides aircraft from one point to another.
4. Locates aircraft with respect to any point on the earth.

In this chapter, radio is treated from the standpoint of popular aviation and its small-scale commercial or semicommercial phases. Large-scale commercial aviation radio uses elaborate facilities together with capable full-time engineering and technical personnel who specialize in the particular needs and services of large and efficient enterprises.

Radio in aviation is coming into universal use more and more, and at many major airports planes are forbidden to land or depart unless radio-equipped, so that they may be properly instructed by the control tower. It has taken much money, experimentation, and the aid of the military and naval air forces to develop aviation radio. In the past, the radio requirements for size, weight, power, and antenna, ability to function in low air pressures, and need for special operating personnel frequently interfered with the pay load that a plane could carry. These

Heliocopter. The arrow indicates the extremity equivalent to shape and dimension of microwave wave-guide antenna. (Courtesy Sikorsky Aircraft, United Aircraft.)

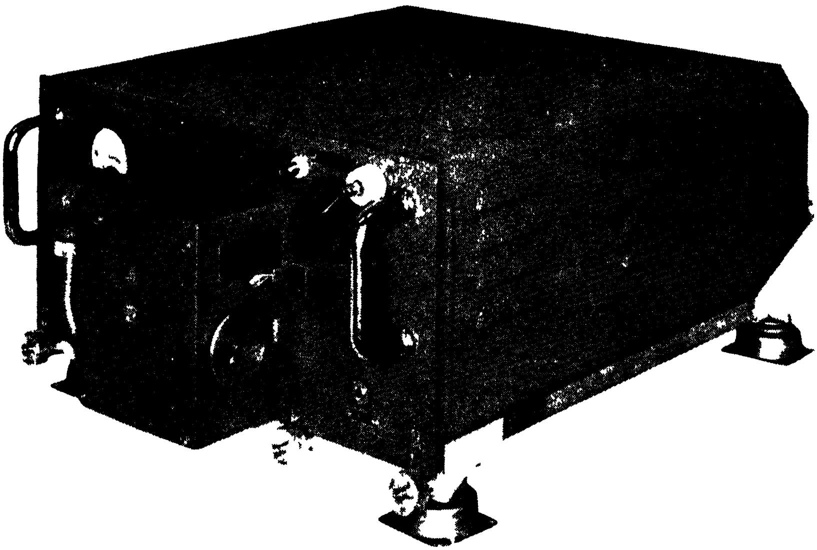
problems are all now fairly well solved and are becoming further simplified by microwave developments.

Popular aviation radio equipment can be used for the following purposes:

1. To receive and transmit weather information.
2. To obtain permission and instructions to land and to depart from airfields.
3. To get traffic directions in order to change course or destination in flight.
4. To avoid collisions and warn other craft.
5. To help planes lost due to poor visibility or faulty navigation.
6. To indicate requirements for fuel or parts, or need for a mechanic.
7. To arrange for connecting transportation.
8. To allay anxiety concerning movements of an overdue plane.
9. Eventually, to talk with anyone within the limits of the radio and connecting wire facilities of the telephone toll system, similar to the marine radiotelephone service.

3 Problems Peculiar to Aviation Radio

For two-way radio to be feasible for popular aircraft, it must take up an unimportant amount of space, be light in weight, and consume little power, so that even the smallest private plane will be able to include the equipment without finding it burdensome. The type of plane under



Modern two-way radiotelephone aircraft equipment for larger planes. (Courtesy Bendix Radio Division of Bendix Aviation Corp.)

consideration is too small to require a special radio operator. As the pilot or a passenger must perform that function, the equipment must be designed accordingly.

The pilot of a modern airplane has innumerable instruments and details to check. Even private planes have gauges to watch which indicate such important information as engine speed, air speed, turn and bank, air bubbles, horizon, trim course, and the like, besides the radio gear itself. In addition, the pilot has to check his navigational charts and the panorama of the countryside for landmarks. Radio must lighten not increase his work load in flight.

A plane flies through the earth's magnetic and electrical fields. It encounters densities of different charge, as well as rain, snow, dust, or hail. These result in noises known as precipitation static which may not exist at nonaircraft radio stations. As the plane when flying is not grounded to the earth, crackling and sizzling sounds can be heard which can even develop into a constant roar. On the lower frequencies utilizing amplitude modulation, reception can become almost impossible. It becomes increasingly annoying as speed increases, and the number of engines on a plane add to the roar. The plane in space is comparable to one plate of a condenser. It is also comparable to an inductance in the earth's magnetic field. Some planes carry a trailing wire to discharge the charge that accumulates in motion. However, many successful communi-

cation flights without such provision have been made by operating on very high frequencies or higher.

Ignition and electrical interference on a plane are much more severe than in most other craft. The noise level in a plane is ordinarily very high, so it is preferable to use a low level or insensitive type of microphone. This makes it necessary to speak close up to the microphone and much louder than normal. This feature enables the microphone to ignore the high noise levels existing in the plane during flight.

A plane operates in areas of variable air pressures, anywhere between 14.7 pounds per square inch at sea level to a pressure much less than that as the plane rises thousands of feet. As the plane gains altitude, the pressure is reduced, and component parts have a tendency to expand and burst or to develop leakage. Insulation begins to break down at lower voltages than it would at sea level. Storage battery electrolyte also expands as altitude increases, as will any kind of liquid or paste. These conditions may be offset in part by reduction in temperature as the plane flies aloft, particularly in winter. However, temperature will not be useful in this regard in warm weather or when the plane is heated.

A plane flies at various angles with respect to the horizontal at various times during landing, take-off, changing elevation, or making a turn. Buffeting winds and air pockets may cause the plane to change its angle briefly or become momentarily unmanageable. During such times, the antenna changes its polarization so that it differs from the polarization at the receiving point.

The equipment undergoes shock and vibration due to the relatively large power plant, light plane construction, and jolts encountered aloft or during a landing.

The power supply is ordinarily limited, so that transmitters are usually of a type employing no more than a few watts of power maximum except in the largest and costliest planes.

4 Design Considerations

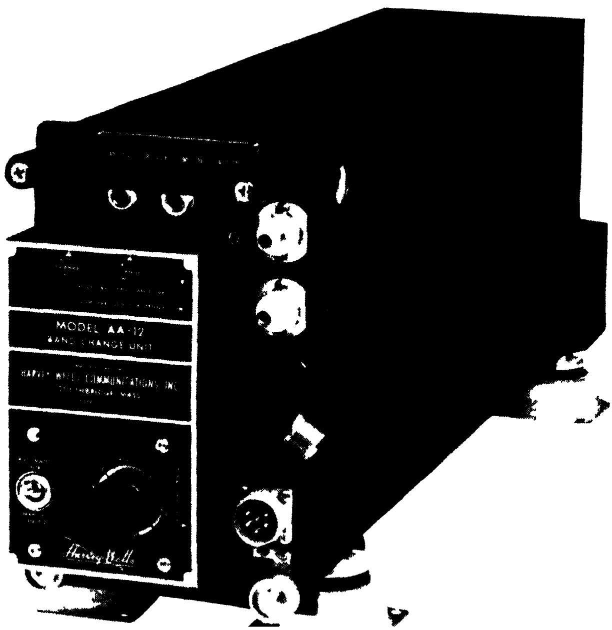
Equipment utilized in popular types of aircraft should first of all be dependable and should be designed with the following points in mind:

1. Low power consumption feasible to provide.
2. Be very light in weight but extremely sturdy, and occupy minimum space.
3. Be extremely simple to operate and quick in response.
4. Be easy to service, remove, or install without disturbing the plane structure.
5. Be low in cost to make possible wide adoption.
6. Be capable of covering the frequency ranges which desired points and services use to transmit and receive.

7. Be flexible enough for various forms of aeronautical intercommunication with other planes and the ground.

8. Have a loop on lower frequencies or a parabolic reflector or directional array on higher frequencies for radio direction finding. It should be sufficiently focused, in the case of the higher frequencies at least, so that a plane can "home" on a signal heard and head for it.

9. Be protected against vibration occurring at any angle. This should cover the range of mechanical or vibratory frequencies which may result from a high-speed powerful engine driving a plane of very light structure.



Multi-frequency aircraft radio receiver used by major air lines. (Courtesy Harvey-Wells Communications, Inc.)

10. Be protected up to several times the weight of the equipment against shock occurring at any angle as the result of air pockets, landing, acceleration, or deceleration.

11. Be able to operate whether plane is flying straight, sideways, or upside down.

12. Should function on radiotelephone, that is, voice.

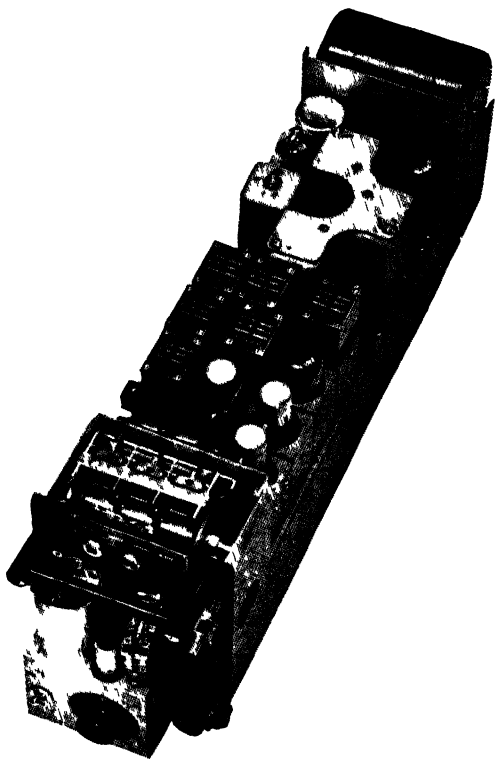
13. Normal transmission and reception should be possible during flight or when engine is turning at cruising speeds, without being excessively hampered by ignition and other electrical interference.

14. The antenna should be rigid and so located that it will have, or can be placed in the best angle to have, the correct polarization of radiation with respect to the points most important and more common to communicate with. It should not be able to change its shape or dimension, due to operation of the aircraft or the effects of weather.

15. The shape, size, weight, or placement of the antenna should not offer such air resistance as to slow the plane markedly or cause it to develop a tendency to fly toward the right or left, or up or down.

16. Equipment should be of such weight and so placed that it will not disturb the plane's center of gravity to an embarrassing degree.

17. Component parts should have an ample safety factor, substantially larger than for equipment used on the earth or at sea level. This is particularly true with respect to insulation and parts containing liquids or pastes.



Interior view of multi-frequency aircraft radio receiver used in major aircraft (Courtesy Harvey-Wells Communications, Inc.)

18. Materials to be used should have maximum strength but minimum weight while still retaining sufficiently satisfactory electrical and physical characteristics.

19. Equipment should be made of selected materials protected against corrosion, or it should be placed where it will be protected from humidity or moisture.

20. Equipment should function in the range of temperatures encountered aloft, particularly during extreme cold, well below zero. A range from 50 degrees below aloft in winter to 125 degrees above on the ground in summer should exist. Aircraft used for special assignments or feats require a range even greater than that. Alaskan winter operations should have equipment designed for 100 degrees below zero Fahrenheit. Operations during summer months in the desert should

have equipment designed to withstand temperatures up to 150 degrees above zero Fahrenheit to take care of extreme exposure to sunlight.

21. Since the material used in aviation equipment has minimum thickness to conserve weight, corrosion can eat through faster. The material should be properly coated or surfaced to minimize this tendency.

22. Emergency or alternate facilities should be included, if possible, to use if main unit breaks down, whether transmitter, receiver, power, or antenna.

23. Equipment should be of a type that can be operated by plane occupants or personnel with minimum distraction, effort, or movement from normal position.

24. Equipment should have minimum extremities, preferably none, such as long trailing wires or antenna hanging behind or below the plane. They tend to get fouled as well as produce plane drag.

25. The antenna should not have to be reeled out in order to provide correct length for resonance, as this means that during landing, unless additional antenna facilities are provided, there will be little or no communication.

26. To prevent possible mishap, no part of the equipment should be allowed to protrude inside the plane.

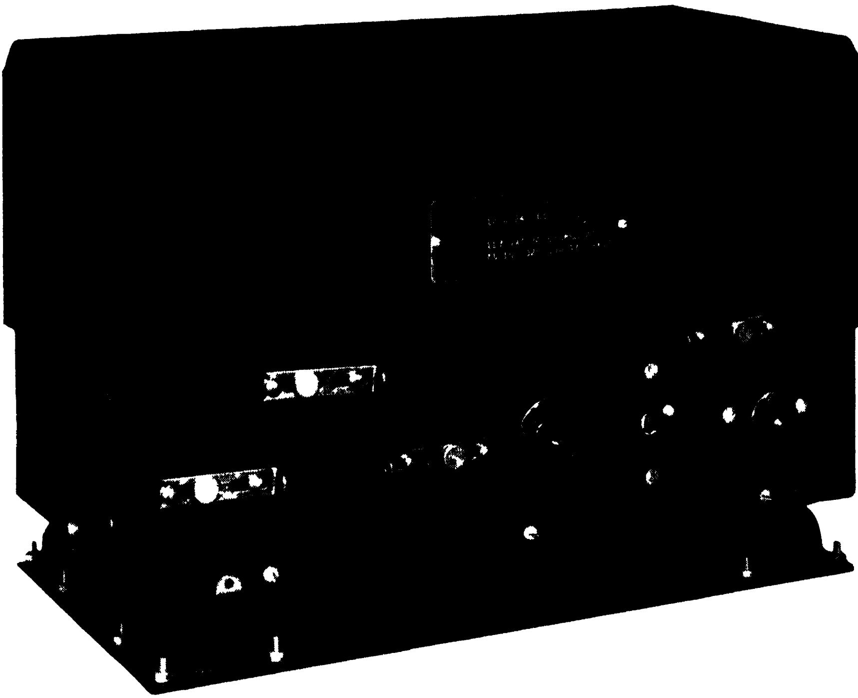
27. Stranded wire should be used instead of solid wire so that it will be less likely to crack or break from movement.

5 Aviation Power Supply

The simplest way to provide power on a plane is to make use of the storage battery already present for engine starting, ignition, and lighting. The storage battery affords power while the aircraft is in flight and while on the ground whether the engine is running or not. To depend only on a generating method geared to the engine or a windstream arrangement is unsatisfactory when the aircraft requires communication when not in flight or when the engine is not running. The generating method should be used for charging the storage battery, and the battery should provide the power for the radio equipment.

The amount of current that can be taken from the storage battery is limited and is further complicated by the fact that as new and additional devices, conveniences, and comforts are added to the airplane the demand for electrical power increases. Most of these developments are either purely electrical or electromechanical in operation. Specifically, electricity on aircraft must be used for (1) starting the engine; (2) retracting or extending the landing wheels; (3) varying the pitch of the propellers; (4) illumination; (5) operating heaters, defrosters, and de-icers; and (6) operating all instruments used in flying the plane, including radio equipment.

The higher the voltage, the smaller may be the diameter of the copper wire used for the power cable. Usually the amount of wire involved is not important for the applications considered in this chapter. Since the aircraft has provisions to charge the battery from either the engine or the windstream, the battery will charge so long as the current drain is less



Power converter using 12-volt or 24-volt storage battery to develop 110-volt 60-cycle AC on aircraft or other vehicles (Courtesy Electronic Laboratories, Inc.)

than the charging rate. When the charging rate is less than the current drain or no charging is possible, then the battery begins to discharge at an important rate. This must be carefully heeded and must not be allowed to run the battery down to a point where it will not be able to function for the next flight or for the remainder of the current flight.

To conserve weight and space, the aviation battery has a low capacity in ampere hours and a short charging cycle. This means it is discharged and recharged much more often and much faster than an automobile battery. The difference may be ten times.

Since the plane is not always in a horizontal position and the storage battery must be securely attached, there is a nonspillable provision for each storage battery cell, so that no acid, or very negigible amounts, will spill or work its way out of the battery when the aircraft takes extreme angles. This is taken care of by providing more clearance between the top of the battery plates with respect to the top of the container. In this space, a nonspillable feature is provided, such as a ball coming up to seal the aperture when the battery is tilted from the horizontal as a result of the plane's flying angle. Upon resuming a horizontal position, the seal

breaks, and the ball no longer blocks the aperture. The amount of leakage which occurs before the ball takes hold is usually too small to cause serious concern. When the ball is not blocking the aperture, gases are allowed to escape during battery charge.

Insulation should be fireproof. Stranded wire is safer than a single solid wire, because the latter will break quicker and more easily under vibration. Stranded wire is more flexible. In the event of a break, only one or a few strands will be affected, except in the most extreme cases, and the wire will still function normally or nearly so.

Copper is the best all-round conductor for aviation from the standpoint of low resistance, cost, availability, and weight. Lighter wire, such as aluminum, can be used, but its resistance is greater, with resulting increased voltage drop per unit length, although the length involved may not make this condition important. To duplicate the efficiency of copper wire, the aluminum wire would have to be thicker in metal and have more insulation reach around its increased circumference. Even then it might have a slight weight advantage but not enough to justify its adoption. A compromise might be to copperplate aluminum wire, since it is the surface of the wire that is important. However, this introduces manufacturing difficulties.

Higher storage battery voltage reduces the current in amperes necessary, and the wire diameter can be smaller accordingly. This saves weight, so long as the voltage is not so high that increased insulation becomes necessary. Usually the minimum insulation provided is adequate to handle the voltage involved, since it may be of the order of 6, 12, or 24 volts. It does not require very much insulation to provide protection against such a low potential.

The small plane uses a 12-volt storage battery, the larger plane, a 24-volt. These appear to be the most advantageous on the basis of weight and the capacity of the aircraft electrical system. The smallest planes will still use standard 6-volt systems, since the weight difference there is not sufficiently important in their application; the wiring run is ordinarily very short. The private pleasure plane does not go to extremes in the conservation of a pound or two of weight, but in the case of the major commercial air lines, statistical experts can develop an extra pound of weight into figures of astronomical proportions representing lost revenue. Prewar, a radio engineer for a leading American air line reported that they were limited to 425 pounds of radio equipment per plane for the most elaborate and largest aircraft used in passenger service. This figure will be increased postwar because of new instruments for navigation, electronic controls, and new interior-exterior communication features, plus the fact that aircraft will increase in size.

Direct-current radio equipment will continue to be the preferred type, since it can be used with the storage battery. A dynamotor and/or vibrator converts this low voltage into the necessary higher circuit voltages. Where AC systems are used on planes, they usually operate on frequencies higher than 60 cycles. A popular frequency is 400 cycles because of the saving in iron for choke and transformer cores. Such special equipment is more costly to provide except where the quantity is sufficiently large for mass production.

6 Radio Performance in Aircraft

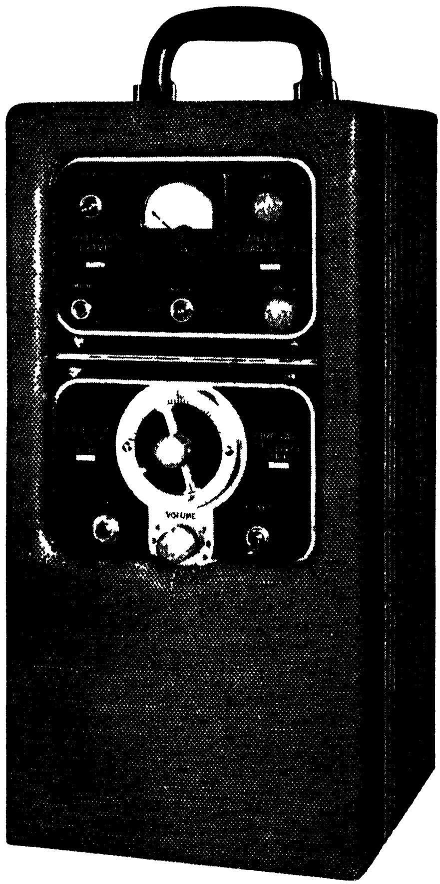
The plane's single and great advantage in radio performance is the fact that it has maximum possible horizons. Its antenna is higher in free space than is possible for any vehicle or fixed station. A plane has the following maximum optical and minimum radio horizons.

Elevation Feet	Visual Horizon 1.225 × Square Root of Elevation Miles	Radio Horizon 1.4 × Square Root of Elevation Miles
100	12.25	14
500	27.32	31.22
1,000	38.71	44.24
1,500	47.41	54.18
2,000	54.75	62.58
2,500	61.25	70.00
3,000	67.09	76.68
3,500	72.47	82.82
4,000	77.46	88.53
5,000	86.61	98.98
6,000	94.88	108.43
7,000	102.48	117.12
8,000	109.56	125.22
9,000	116.20	132.80
10,000	122.50	140.00
15,000	149.94	171.36
20.000	173.24	197.99

The figures above are based on the horizon enjoyed by a plane aloft with respect to a point at sea level. It will be greater where the other point has some elevation; then the horizons of both points are added to make the total figure. For example, between two aircraft aloft, one flying at 2500 feet and the other at 3500 feet, the horizons compute as follows:

Elevations of Two Planes Feet	Optical Horizon Miles	Radio Horizon Miles
2500	61.25	70.00
3500	72.47	82.82
	133.72	152.82

In making horizon computations, do not add the elevations of the two points before obtaining the square root. They must be computed separately and then added together. For example, in the above computation, if the elevations of the two planes had first been added together, and the figure of 6000 feet were used to represent the combined height,



Portable aircraft equipment for intermittent use in small aircraft. (Courtesy Jefferson-Travis)

the result of the computation would be 94.88 miles instead of 133.72 and 108.43 miles instead of 152.82.

As optical horizon is dependent on visibility, which in turn depends on fog, mist, clouds, or darkness, the optical figures are the maximum possible with the minimum liable to approach zero at times. The radio horizon is independent of visibility, so that the ranges given are minimum

and likely to be exceeded when intervening conductivity is improved by conditions other than a clear atmosphere.

In February, 1941, radio horizon ranges in accordance with the tabulations above were confirmed for elevations up to 9000 feet. The test was conducted in a Stinson monoplane belonging to the Inland Fish and Game Commission of the State of Maine, piloted by the head of the Civilian Air Patrol and witnessed by the manager of the CAA Airways radio station in Augusta, Maine. The test was conducted with modest equipment, hastily and not specially or ideally installed. Following are the test provisions:

Transmitter: Harvey-Wells AM-10. Ten watts amplitude modulation.

Receiver: Harvey-Wells 4-tube superregenerative type.

Area of operations: Between Augusta Airport, Thomaston-Rockland-Camden Hills and Belgrade Lakes, all in Maine.

Temperature on ground: About 30 degrees Fahrenheit.

Temperature aloft: As low as 10 degrees below zero.

Weather: Sunshine or overcast.

Duration of test: Two hours continuously at various levels, routes, and speeds up to about 200 miles per hour.

Power supply: 6-volt storage battery.

Antenna: Random piece of wire, 6 feet long, partially running from set to doorway with remaining 3 feet hanging outside with door edged on it but kept fairly rigid with a fish lead at end. Allowed to hang and sway freely.

There was little time to make special installation provisions, and it was not desired to mar the plane in any way, as the equipment was not to remain in the plane. The equipment was set on the floor in front of the operator.

An effort was made to contact WSWD Wells, Maine, state police barracks on 39,900 kilocycles amplitude modulation, with the station using 25 watts and a similar receiver. The plane kept increasing altitude until, at about 6200 feet and an air-line distance of 99 miles, actual two-way communication was established. Stations could be heard weakly before that, but identity had not been certain. Communication from then on was maintained without difficulty to any increased level attempted (9000 feet maximum). Signals were markedly louder in some directions at the threshold, that is, in the region of 6000 feet elevation. Above that level, communication was satisfactory in any direction, although better in some directions. Best communication apparently depended on the antenna lead having the angle most closely corresponding to the other station's antenna.

No difficulty was encountered in communicating with any fixed or mobile unit within that area. All cars available on the highways, which at the time did not happen to be more than 50 miles away, reported

excellent signals both ways; a specific case being between the plane at any level with a state police car using identical equipment operating in the vicinity of the U.S. Veteran Hospital at Togus, Maine.

Due to battery weakening without being recharged, since it was not connected to a generator and had to operate half the time with a transmitting load of 22 amperes and the rest of the time with a receiving standby load of 6 amperes, and due to the poor antenna, absence of ground, makeshift adjustment, and the like, the 10-watt transmitter efficiency was probably reduced to that of 1 or 2 watts on the ground. FM would have definitely improved the performance. Although the plane was bonded and shielded, the equipment itself was not.

The tests confirmed the horizon theory and indicated that for direct path communication not dependent on ionospheric reflections, the range will increase with elevation and that it is greater than the optical horizon, just how much more depends on the correctness of installation and the efficiency of the antenna system and equipment, and only to a limited extent on the power. The tests also indicated that for elevations up to 9000 feet ordinary component parts of reasonably good ratings, rather than of outstanding quality and specially oversized, would suffice. The exact equipment and component parts described in Chapter Seven were used in this test.

Other tests dating back as far as 1935, conducted at radio amateur conventions and field meetings at the Hyannis Airport by the Cape Cod Radio Club, provided excellent communication with homemade transceivers of 1 or 2 watts power or even less in accordance with the same horizon computations. There it was done on frequencies between 56 and 60 megacycles. Good communication was possible between a plane en route from Brockton, Massachusetts, to Cape Cod over Massachusetts Bay and individual amateur radio cars at the airport. Other tests were plane to ground, plane to plane, plane to cars, and plane to persons walking with self-contained equipment. In all cases, any equipment in normal operating order was capable of exceeding the maximum visual horizon. Furthermore, it could be done with less efficient AM equipment as well as with FM. Increasing the power largely manifests itself as increased signal strength within the horizontal limits, with little additional communication range added beyond the horizon.

It is therefore felt that in every case maximum elevation means maximum signal strength and maximum range. Elevation outweighs every other consideration, so long as the equipment is functioning normally.

Next in importance is the antenna system. It may be small if necessary, but it should resonate with the transmitting frequency. The plane antenna can be designed along the same plan as used for any other type

of mobile station, modified only to suit the particular plane installation. Typical antennas used on aircraft are:

Low or Medium Frequencies (Long Range). Antenna reel with aerial wire reeled out as long as necessary to produce resonance.

Low or Medium Frequencies (Short Range). A short antenna run from cockpit back to the tail fin, with its short length compensated for by antenna circuit loading. This is not efficient but is useful for a few miles despite the low frequency and very low transmitting power in the plane. Used principally when regular antenna is reeled in.

Very High Frequency (Horizontal Ranges). A quarter-wave length antenna, vertical or approximately so, depending on desired plane of radiation, coupled by a flexible coaxial cable to the equipment. If quarter-wave length is too long physically to provide, some loading is provided at the equipment with somewhat reduced efficiency.

Microwaves (Unobstructed Horizontal Ranges). On the ultra-high-frequency spectrum, a series of antenna elements may provide directivity and power concentration for switchover to either side of plane for homing or directional uses. On the super-high-frequency spectrum it is usually a parabolic reflector or an electromagnetic horn made up from simple wave guide. This can be designed for any amount of beam or radiation width from a whole sphere to a few-degrees conic beam. A typical case might be a 12-inch to 36-inch parabolic dish reflector inside the plastic shield of the plane. The attenuation existing within the plane may be preferable to the corrosive and other effects resulting from mounting this outside the plane, so long as it is not fully shielded by metal. Plastics, such as polystyrene, have a dielectric constant that approaches air and offers little attenuation when mounted within such protection.

7 Noise Suppression

Early planes, made of wood and having spark plugs and cables unshielded, developed terrific electrical interference that came in on the radio receiver with a constant roar, so long as the engine was running. It was of such magnitude that all reception, even locally, was impossible. However, transmission was still possible, although the interference would manifest itself to some degree as background noise. In effect, the signal-to-noise ratio was completely unfavorable.

Disturbances to radio reception in a plane may come from the following sources:

1. Precipitation static which will be maximum on low or ionospheric frequencies and minimum on high or direct path frequencies.
2. Ignition interference where every spark plug makes a too ideal spark transmitter that will produce terrific interference for its range of frequencies.
3. Electrical system radiation.
4. Intermittent contact between various portions of airplane structure.
5. Hash resulting from rotational equipment.

6. Other forms of static, including lightning, that may originate from considerable distances and be picked up for ranges comparable with normal radio communication.

In the modern plane, the ignition system is shielded within a harness. The undesired interference passing along the wire contained within the shield is varying or erratic and sets up a field by induction within the shield. The currents flowing in the shield develop a counterfield opposite in direction to that which developed it, thereby tending to cancel or neutralize the interference. The shield does not function 100 per cent perfectly in practice, since it is difficult to match it that carefully; but it does definitely bring interference down to a point where it becomes unimportant or unobjectionable. This shielding harness has to be complete, or it loses much or even all of its value. Even a small opening or break in the shield of a fraction of an inch to disturb its continuity can bring back interference as bad as if no shielding existed. If shielding fails to cure a certain installation, it is because of incompleteness, and some radiation outside of the shield is taking place.

Bonding is also frequently necessary on a plane, particularly if the plane is not made entirely of metal. This bonding needs to be made between the various metallic members scattered throughout the plane to provide a continuous path. This continuous path is considered to be the equivalent of a ground in a plane. Even in a metal plane, it may be necessary to bridge two moving surfaces with a conducting jumper. If these parts are not bonded to each other to form a continuous electrical conducting path, a difference of charge developed between them may produce a spark. The gasoline tank should be bonded particularly because of this danger, which is a hazard even when no radio equipment is aboard. Items not bonded near the spark plugs may serve as antennas, radiating as spark transmitters into space. Bonding may need to include a flexible jumper such as copper braid between wing and ailerons, and between tail fin and rudder.

It is usually expensive to provide this bonding once the plane is built, as it requires getting under the skin or sheathing of the plane for a good part of the undertaking. In purchasing a plane, it is poor economy to buy one that is not shielded or bonded. The factory job done at the time of the plane's fabrication is superior as well as more economical. Its additional cost, where imposed, can be compensated in part by the use of less costly radio equipment, as greater efficiency is attained than would otherwise be possible. The finest equipment in an unshielded and unbonded plane is much inferior in performance to the most modest equipment enjoying such provisions.

Prewar FM made little headway in aeronautical applications, despite

the many advantages it has for aviation. This was largely due to the fact that good communication systems were already established, despite many problems, with amplitude modulation techniques. It was also due to the fact that low or medium frequencies were being used with insufficient spectrum for ideal FM deviation ratios. Airports have been operating on 278 kilocycles, while aircraft have been using 3105 kilocycles at night and 6210 kilocycles daytime, depending on sky-wave reflections for great ranges. This situation will change as higher-frequency spectrums are utilized. Aviation can effectively use microwaves in conjunction with FM and overcome many of its radio communication problems of the past. This is based on the assumption that the aviation radio groups will be willing to abandon or supplement the techniques they developed prewar and shift from sky-wave frequencies to ground-wave frequencies. They can effectively do so for the following reasons:

1. The frequency spectrum in microwaves is comparatively unlimited.
2. FM with high deviation ratios will have characteristics that widely differ from the interference noises developed by a plane in flight. This will greatly minimize interference and increase intelligibility.
3. At such frequencies, lightning and static should be minimum in its effects, or absent.
4. Equipment will be small and inexpensive.
5. Directive antenna provisions will ignore interference and avoid energy dissipation in all parts of the sphere except in the desired narrow-focused beam of a few degrees.
6. Less elaborate shielding and bonding provisions will be necessary, saving cost, material, and weight. Perhaps with metallic construction and compartmentation, shielding and special bonding may eventually be entirely eliminated and ignition interference be undetected on high frequencies.

In an aircraft in motion, the noise level may be too high to use a loudspeaker except in soundproof cabin planes. Headphones are usually employed. This also furnishes assurance that the communication will not be missed. There may be more than one pair in parallel to permit more than one person to listen at the same time.

Since the plane has such high noise levels, the microphones should be of a type too insensitive to pick up anything except at a high input level. This high level is obtained by speaking loudly into the microphone or by bringing the microphone close to the speaker's lips. Carbon microphones are most sensitive but have less reproduction quality; however, it is ample for voice. If amplification is permissible, as well as the slightly increased amount of space, weight, power consumption, complexity, and parts this entails, it may be advisable to use a noncarbon type of microphone. The conventional carbon type has a tendency to pack its carbon granules, due to vibration, and may need to be shaken slightly at times.

If desired, the interphone communication system in the plane can be connected directly to the radio equipment, so that each person on that system can listen or talk through the radio equipment.

8 Direction Finding

In addition to radio direction finding for marine applications, discussed in Chapter Fifteen, the following is peculiar to aeronautics alone.

Aviation Radio Beams. The Civil Aeronautics Administration operates radio aids to aviation along principal air-line routes in the United States. By the use of special antenna facilities at transmitting points, usually at or near major airports, signals are sent out along direction paths which serve to guide radio-equipped aircraft along their routes, regardless of visibility.

Such radio aid consists of transmitting two narrow beams of radio signals. One beam is sounded dot-dash (dit-dah) while the other beam is sounded dash-dot (dah-dit). When a plane is on course and flying between the two beams, the dit-dah and the dah-dit are heard together, resulting in a steady tone being heard (dahhhhhh). If the plane veers off course, it hears either dit-dah or dah-dit. If it hears dit-dah on one side, it swings back on course until it hears the steady tone again. If it goes too far over, it will hear the dah-dit. The dit-dah is the letter A in the telegraph code, while the dah-dit is the letter N. About every half minute the station sending these radio signals will interrupt its transmissions with the call letter abbreviation for that station, facilitating identification, and avoiding possiblity of following the wrong airway beam.

When directly over the transmitting antenna, a small zone of silence in which no signals are heard can be noted. It is cone shaped with the zone increasing in area the higher a plane is in the air, diminishing to negligible proportions close to the ground.

Generally speaking, the cone of silence depends on the height of the plane over the radio station, while the width of the beam depends on distance from the same station.

Aviation Radio Compass. Aircraft are also equipped with radio direction-finder receivers similar to but lighter and more compact than ship types. Such equipment can be used to determine the direction of any signal heard on the air and, if desired, to enable the aviator to steer straight for it.

For aviation services, the above information should be supplemented with and checked against engine speed, weather conditions, landmarks, weight load and trim, altimeter, air speed indicator, drift indicator, and such other aids or indicators as may exist in a modern plane.

CHAPTER SEVENTEEN

PERSONALIZED APPLICATIONS

1 Two-way Radio for Doctors

Many doctors, particularly in smaller communities, have considered the possibility of equipping their homes, offices, and cars with two-way radio facilities, as the need for their services is unpredictable and frequently very urgent. Much of the doctor's time is spent in traveling to and from patients or a hospital. During this traveling time, he may be inaccessible, and emergency calls to his office must wait until such time as he can be reached by telephone.

Two-way radio facilities will enable the doctor to keep his office or home constantly informed of his movements. In actual travel, he can be reached via his automobile receiver and can be directed to an emergency case or a near-by call, or be diverted from a less important call to a more urgent one. Two-way radio is also of value in a joint medical practice and for situations requiring the services of more than one doctor.

There are about 170,000 doctors in the United States and about 12,000 doctors in Canada. The greatest amount of geographical area is served by rural doctors who are general practitioners. Each serves an area of many miles, much of which may be isolated and not readily accessible for other forms of communication. Frequently the doctor may be wanted in the vicinity through which he is traveling from one call to another.

The cost of radio facilities, if it should be considered a factor, can be readily met from the increased calls a doctor can handle and subsequent fees. Although it is technically possible and even feasible for each doctor to own a complete private radio system that might cost from $200 to $1000 to provide two-way communication between home, office, and car, it is preferable for such facilities to be part of a unified medical radio communication service embracing all activities within a county or group of adjacent communities or even a single community This would comprise:

1. Hospital as the master radio station manned twenty-four hours a day, to receive and dispatch messages. There should be emergency electric power, so

that communication can be maintained with cars having their own storage battery power, regardless of any breakdown in electric power or normal wire communication.

2. Ambulances.
3. Doctors' automobiles.
4. Doctors' homes or offices (optional).
5. Undertakers' offices or vehicles.
6. Public health officials of the county or community.
7. Traveling nurses.
8. Red Cross.

This should be a unified system operating on a single frequency, so that there can be communication between the master station and mobile vehicles and also between the vehicles themselves in any manner of combination. This would greatly simplify dispatching, as in some cases the doctor would not always have someone at home or office to handle calls. The public or the telephone operator could call the master station to relay a message to the doctor. The master station would always know where each doctor could be reached, and if he is inaccessible or unavailable could dispatch another doctor. In that way, doctors could maintain their private practices and yet more effectively handle all the needs of their area. Simple codes could be developed by each doctor to safeguard confidential information.

2 Hospitals and Ambulances

For approximately every twenty doctors in the United States and Canada, there exists one hospital. The total number of hospitals is about 7000 in the United States and 800 in Canada. The larger hospitals maintain from one to several ambulances each.

Ambulances should all be equipped with two-way radio. Already many radio-equipped ambulances are operating in conjunction with police or fire radio systems for lack of a better tie-up. There should be at least one radio-equipped ambulance in a community. If the community is too small, then one should be available for a reasonably sized area.

Many hospitals do not have enough ambulances, or a community or several communities may jointly possess only one. It is therefore desirable that an ambulance can be contacted while it is away from the hospital. If the ambulance should break down or even have a flat tire, arrangements can be made for transferring a serious case if necessary. Ambulances usually travel at high speed and have to maneuver in traffic which may cause them to be involved in accidents requiring radio calls for assistance themselves. Frequently they have to proceed at times or in places under conditions when nothing but independently powered two-way radio facilities will suffice to receive or transmit necessary infor-

mation. Even if telephones are available, the likelihood of having access to one after midnight is very small and in any case inconvenient, particularly in a lonely area.

When emergencies arise, two-way radio helps to co-ordinate the services of all doctors and nurses, ambulances and hospitals, and relief organizations. It expedites obtaining blood donors and blood plasma of rare types for transfusions.

Complete two-way radio communication facilities to cover all such situations include:

1. Medium-frequency marine radiotelephone type of equipment, from master or fixed points to any other point.
2. Very-high-frequency equipment such as used by police and fire departments.
3. Microwave equipment on frequencies exceeding 300 megacycles where little difficulty would exist in providing sufficient frequency spectrum for an independent system, particularly one operated by an individual doctor or activity.
4. Induction radio on low frequencies dependent on the presence of wayside wires for most of the distance.

The purchasing cost of such equipment will be between $100 and $500 per station. The servicing and parts replacement cost should not exceed $5 a month per station under contract, except in isolated instances. Costs both lower or higher than these are possible depending on the type of equipment selected and the tie-up and scope of the facilities.

Any of these facilities can be planned to accommodate the area and service requirements involved.

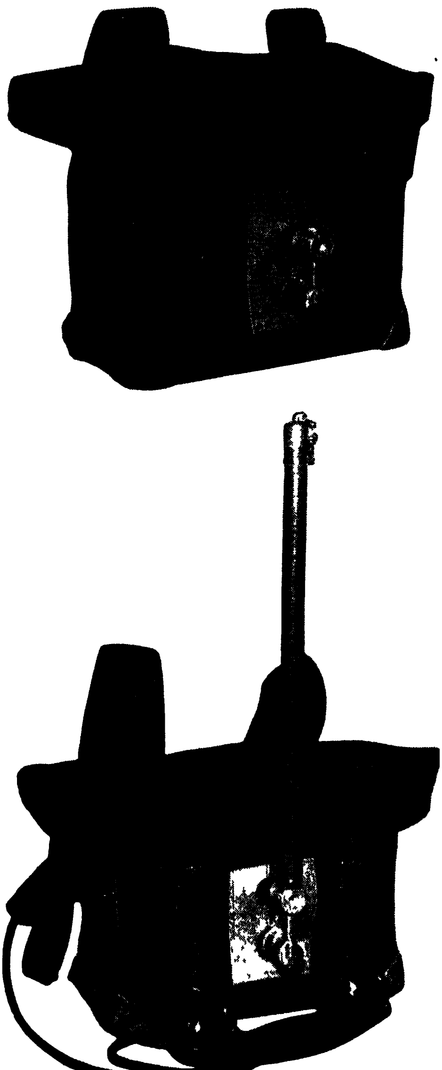
3 Private Automobiles

This is the field of application where the greatest number of units could exist. Heretofore, except for amateurs or persons having some official connection with a public agency, such use of two-way radio has been prohibited because of lack of frequency channel space.

Two developments now make it possible to provide the private automobile with two-way radio despite the fact that there are some 25,000,000 such vehicles that might be eligible in the United States alone. These are:

1. Microwaves having virtually unlimited frequency spectrum because of the high over-all frequency spectrum existing on wave lengths shorter than one meter. These frequencies can be utilized over again every few miles of distance in every direction.
2. Induction highway radio equipment which utilizes the induction field that manifests itself between railroads and wayside telephone, telegraph, or specially provided wires, and also prevails between vehicles on most highways and such wayside wires.

The applications of such facilities in the private passenger car may be essential or nonessential. In any case they will be convenient and economical and relieve anxiety on innumerable occasions.



Link type 695-B pack set showing two-way radiotelephone with telescopic antenna. (Courtesy Link Radio Corp.)

4 Radio Amateurs

Nearly every two-way radio use, particularly all the personalized applications, have been available to radio amateurs for many years. In fact, they have shown us the way to do things in a versatile and economical fashion. Persons interested in the various uses of radio should give it serious consideration as a hobby. Things that cannot be done legally or technically as a professional or a layman are usually possible for a legally licensed amateur.

Persons interested in amateur radio activities should first write to the American Radio Relay League, West Hartford, Connecticut, for literature on becoming an amateur. For about $2.50 a year, any person can join the league as a member or associate member and receive free the monthly magazine, "QST." (QST is the old international call meaning "general call to all stations" in any language using our form of alphabet.) The league publishes an annual handbook for about $1 and various smaller instructional pamphlets selling for 25 or 50 cents. In addition, any person may write or visit the Federal Communications Commission, Washington, D.C., or any field office, to obtain printed material on the procedure and requirements for an

amateur radio license or an amateur radio station license. Additional pamphlets on various subjects of radio interest may be obtained for 5 or 10 cents by writing to the Superintendent of Documents, Government Printing Office, Washington, D.C.

The radio amateur is permitted to use various bands of frequencies in the medium, high, very high, ultra high, and super high spectrums. He cannot have an exclusive clear channel, but he can have a wide selection of bands to choose from and can use any or all of them as he may wish, so long as there is no improper or illegitimate usage and no compensation whatever is accepted for his radio activities even if valuable and useful to someone.

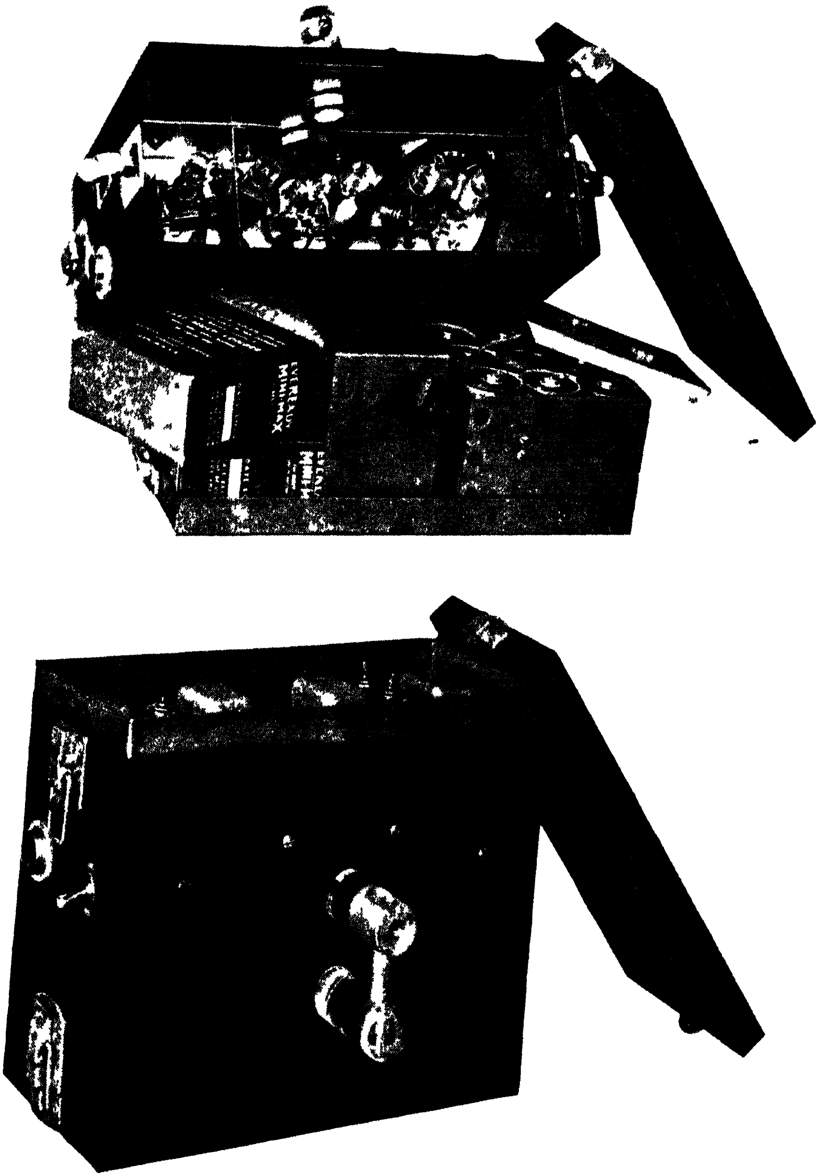
For years, amateurs have enjoyed the following privileges:

1. Personal noncommercial communication, unlimited in nature or amount, anywhere in the world on high frequencies.
2. Communication with their own car, plane, boat, home, or walkie-talkie in any manner of combination on frequencies exceeding 56,000 megacycles.
3. They have been able to buy any common radio item and use any patent without paying specific royalty and to build or rebuild radio equipment so long as it was used in amateur forms of communication not involving compensation.
4. They have belonged to radio clubs and organizations and have established contacts and friendships both local and worldwide.
5. They have acquired much proficiency and competence in radio, electricity, electronics, magnetism, and simple mechanics in the course of pursuing this hobby; all of which is invaluable in subsequent education involving physics, mathematics, optics, or engineering.
6. They have become valuable members of the national defense and are assured interesting opportunities for employment in time of peace and for higher rating or preferred rank in the army or navy in time of war.

Prewar there were about 60,000 amateurs in the world, of whom about 50,000 were in the United States. Postwar this figure may exceed 250,000 and eventually go much beyond that number. There is no reason why it will not reach millions as new microwave frequency spectrums makes it possible to accommodate more stations.

5 Farmers

Two-way radio can be used in various forms on the farm. Most farms operate as a family enterprise with major dependence on one man, who at times, particularly during the planting and harvesting seasons, could use several men. The average farmer has many tasks and chores that vary with weather and unpredictable conditions, so that he is unable to plan ideally for every situation that may arise. He consumes much time in covering the various sections of his farm when he has no means of delegating errand jobs to others.



Link type 695-B pack set showing two-way transmitter/receiver and power supply interior components (Courtesy Link Radio Corp.)

The farmer can have a small handie-talkie or walkie-talkie to be carried on his person. It is battery operated and weighs as little as 5 pounds and occupies little space. Or he can have an equipment that can be energized from his tractor, truck, or automobile storage battery like any other mobile two-way radio. This enables him to do any of the following:

1. Communicate with the house while in his truck or car on the farm or on the highway.
2. Maintain communication between vehicles on the farm in order to co-ordinate the work.
3. Use the radio equipment as an auxiliary means of communication where telephone is inadequate or nonexistent.

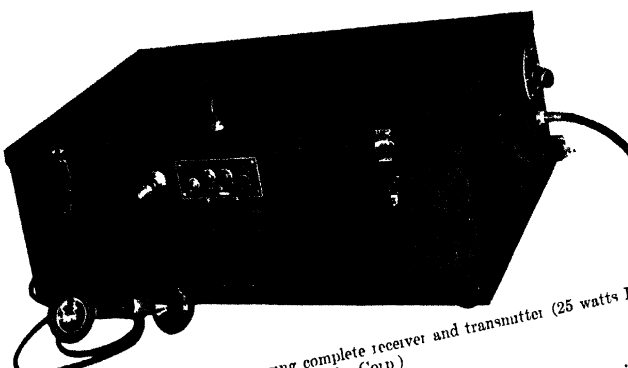
6 Disaster Setup

When serious disaster strikes, such as hurricane, flood, earthquake, and fire, there must be immediate mobilization of the Red Cross and all available medical, first aid, and community relief organizations. Power and telephone lines are usually disrupted, bridges destroyed, and highway and railroad travel blocked. Radio then becomes the only means of communication until normal conditions can be restored.

At such times, two-way radio equipment located in automobiles, which operates on storage batteries, and self-contained walkie-talkie equipment carried by individuals are of the utmost importance. They repay many times what they cost.

Disaster setups can be planned in advance, so that administrative officials will have immediate command of such facilities as are listed here. There should be trained personnel familiar with the technique of operation and periodic drills using these facilities in order to be prepared for any emergency.

1. Record of (a) all fixed stations available if power is functioning; (b) all fixed stations that have their own power plants; and (c) all fixed stations that can be put back into service by auxiliary power and what will be required.
2. Emergency power plants.
3. Mobile radio stations that are self-contained in all respects within vehicles.
4. Mobile station equipment that can be removed and set up at fixed stations to operate with storage or dry battery power but with the extended range made possible by the fixed station antenna or vantage point elevation.
5. Pack sets that can be carried and utilized anywhere.
6. Small handie-talkie or walkie-talkie sets that can be carried on the person and permit communication without impeding other tasks.
7. Spare storage batteries or means to recharge them.
8. Spare dry batteries of the right type or facilities at hand to quickly tie together any available flashlight or dry cell batteries and build them up to any desired voltage values in series and parallel combinations.

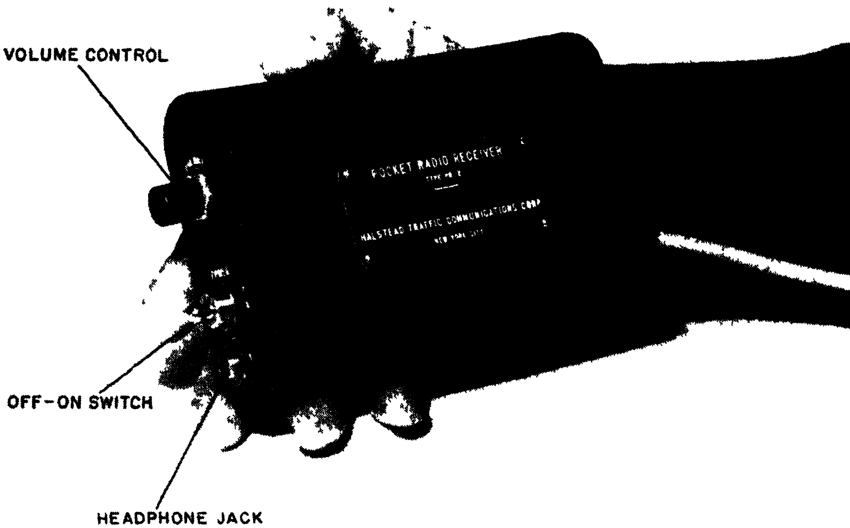


Link FMTR-W equipment comprising complete receiver and transmitter (25 watts FM) in special portable case (Courtesy Link Radio Corp.)

9. Frequency plan.
10. Record of supplementary aid available from other communities in an emergency.

7 Vacation and Recreation Uses

Two-way radio can add to the enjoyment of recreation and vacation days. It will be useful in (1) camps distant from community activities; (2) when hiking, boating, or canoeing, particularly if isolated in unpopulated areas or because of storm; (3) sightseeing by automobile,



Pocket radio receiver. (Courtesy Halstead Traffic Communications Corp.)

bicycle, or motorcycle; (5) flying; (6) hunting and fishing, for communication between members of the party.

The simple lightweight walkie-talkie and the smaller handie-talkie are excellent for such limited use. A spare set of batteries can be taken along. Ordinarily with intermittent usage, one set of batteries will last an entire vacation, and the same unit can be used for any of the applications mentioned above. The higher the elevation of the terrain at the transmitting and/or receiving points, the farther will the communication be effective. In practice, it will be from 1 mile to 25 miles under the usual conditions encountered. In clear spans across water or level country, it will be effective for 2 to 5 miles, increasing with elevation.

This type of equipment will become increasingly inexpensive for the simpler applications until it costs no more than the conventional small broadcast radio receiver.

8 Citizens Radio Communication Service

To provide for individuals who might henceforth desire two-way radio facilities as a necessity, a convenience, or a novelty in utilizations other than already anticipated or specifically provided for, a new Citizens Radiocommunication Service has been promulgated by the Federal Communications Commission.

This new service was officially proposed January 15, 1945,[1] and sub-

[1] FCC Docket 6651, "Report of Proposed Allocation from 25,000 Kilocycles to 30,000,000 Kilocycles," Jan. 15, 1945.

sequently confirmed May 25, 1945,[1] by the FCC. It introduces a new era in radio development in that the general public henceforth may transmit, as well as listen to, radio communications. It commences operations, right from the start, on the microwave band, thereby permitting future expansion without the danger of early equipment obsolescence. The exact FCC report and decision establishing this service is quoted below.

The development of light-weight portable short-range radiocommunications equipment of the "walkie-talkie" type has opened the door to a large variety of new private applications of radio. The success of such communications on the battle front has been followed by many suggestions for peacetime use of low-power portable transceivers in the cities, on the highways, and in rural areas. To make possible the fullest practicable development of private radiocommunications within the limits set by other demands for assignments in the spectrum, the Commission on its own motion proposes to allocate the band from 460 to 470 megacycles (460,000 to 470,000 kilocycles) to a new "Citizens Radiocommunication Service."

The possible uses of this service are as broad as the imagination of the public and the ingenuity of equipment manufacturers can devise. The citizens radiocommunications band can be used, for example, to establish a physicians' calling service, through which a central physicians' exchange in each city can reach doctors while they are enroute in their cars or otherwise not available by telephone. Department stores, dairies, laundries and other business organizations can use this service in communicating to and from their delivery vehicles. Similarly, it can be used in communicating to and from the trucks, tractors, and other mobile units operating in and around large industrial plants and construction projects—many of which spread over a number of square miles. It can be used on farms and ranches for communications to and from men in the fields; on board harbor and river craft; in mountain and swamp areas, etc. Sportsmen and explorers can use it to maintain contact with camps and to decrease the hazards of hunting, fishing, boating and mountain climbing. Citizens generally will benefit from the convenience of this service by utilizing two-way portable radio equipment for short range private service between points where regular communication facilities are not available. During emergencies when wire facilities are disrupted as a result of hurricane, flood, earthquake, or other disaster, the service, as has been demonstrated by the amateur service, will be of inestimable value.

Separate allocations are being made for urban and for rural transit radio communications, which will be available for communicating with city or intercity buses, trucks, taxicabs, etc. These services may develop on a common carrier or private basis on the frequencies set aside for those purposes. In either event, the citizens radiocommunication band will be open to taxicabs, delivery vehicles, or other mobile units, as well as for incidental communication between fixed points.

Common carrier operation in the citizens radiocommunication band will not be permitted, and no charge can be made for the transmission of messages or use of the licensed facilities. The service will thus be for the private use of the licensee

[1] FCC Docket 6651 in the matter of allocation of frequencies to the various classes of non-governmental services in the radio spectrum from 10 kilocycles to 30,000,000 kilocycles. "Report of Allocations from 25000 kc to 30,000,000 kc," May 25, 1945.

who will be responsible for the use of the facilities under the regulations to be promulgated by the Commission.

The 460–470 megacycle band which the Commission proposes to allocate for this service is essentially adapted to short-range communications, and as such, is admirably suited to the uses proposed. The rules will permit the use of "booster" or automatic relay installations where necessary. It is anticipated that most transmitters on this band will be of low power and will not utilize extreme antenna heights. Higher power may be permitted in rural areas where no interference will result.

The design of equipment for use in the citizens radiocommunication band should challenge the ingenuity of radio designers and engineers. A combination transmitter and receiver of reasonable weight can no doubt be mounted in a suitcase; a broadcast receiver, an alarm system, remote control systems, and other devices can perhaps be added to meet particular needs. By keeping the rules and regulations to a minimum, the Commission hopes to encourage ingenuity in design and in utilization.

As in the case of the amateur service, the Commission proposes to assign no channels within the band. It is reasonable to suppose that most equipment will utilize a channel of 150 kilocycles more or less, making possible some 60 or 70 channels; but, as in the amateur band, these matters will not be determined by rule or regulation. It should be possible by the use of comparatively simple circuits already known to provide both transmitters and receivers tunable over all or most of the 460–470 megacycle range and emitting signals sharp enough to minimize the interference.

The bands both above and below 460–470 megacycles are assigned to other services; but the allocation is such that if the utility and requirements of citizens radiocommunications warrant, the band can at some future time be expanded. Alternatively, if a demand for assignments in this band does not arise, the band can be reassigned to another service at a later date.

The essence of this new service is that it will be widely available. Accordingly, only the minimum requirements of the Communications Act plus a few minimum traffic rules will be set up. Operator licenses will be granted only to citizens of the United States. To procure such a license, the applicant need only show familiarity with the relevant portions of the Communications Act and of the simple regulations governing this service. No technical knowledge will be required. It is hoped that the license can be in the form of a small card, with the operator's license on one side and the station license on the other, and that these will remain in force for five years with simple renewal provisions. Station licenses will be limited to point-to-point, fixed point-to-mobile, mobile-to-mobile, and multiple-address communications; broadcasting is not contemplated.

A concomitant of the widest possible availability is that particular licenses are not accorded protection from interference. A license in this service does not guarantee the right to a channel; it affords rather an opportunity to share with others the use of a band. The success of this arrangement in the amateur bands gives every reason to believe that it will be equally successful in the citizens radiocommunication band. In the event that intolerable abuses arise, the Commission will of course take steps to eliminate them. The 10,000 kilocycle width of the band will no doubt be sufficient, however, to make possible simultaneous and efficient use of the limited-range service for many purposes, with serious interference limited to few if any parts of the country.

In any areas where serious interference is experienced, it is the expectation of the Commission that various users of the band in a particular community will jointly seek, perhaps through local organizations similar to the American Radio Relay League in the amateur field, cooperatively to solve local problems of interference and to ensure maximum utilization. The new service is essentially a *local* service; the problems will differ widely in an urban and rural area, in the mountainous west and the flat middle west, etc. The Commission is prepared to cooperate with local groups which may be formed in the working out of cooperative arrangements and it will resort to limiting regulations only in the event that an imperative need is shown.

9 Telephone Company Toll Radio Service

A general mobile radiotelephone service to bring the advantages of two-way voice communication to drivers of motor vehicles was announced by the American Telephone and Telegraph Company on June 29, 1945. The following information was furnished by that organization for inclusion in this book.

Applications have been filed with the Federal Communications Commission for authority to install radiotelephone stations in the following cities: Baltimore, Chicago, Cincinnati, Columbus, Denver, Houston, Milwaukee, New York, Philadelphia, Pittsburgh, St. Louis, Salt Lake City, and Washington, D.C.

In addition, surveys are continuing to determine the early need for and the feasibility of mobile radiotelephone service in many other cities of the country, including Akron, Atlanta, Beaumont, Birmingham, Boston, Cleveland, Dallas, Dayton, Des Moines, Detroit, Fort Worth, Green Bay, Indianapolis, Kansas City, Little Rock, Los Angeles, Louisville, Memphis, Miami, Nashville, Newark, New Orleans, Oklahoma City, Portland, Oregon, Providence, San Antonio, San Francisco, Seattle, Toledo, Tulsa, and Wichita. The Bell System companies plan to make the new service available first in cities where public necessity is greatest. Eventually it can expand to provide complete coverage throughout the nation.

Telephones on automobiles, trucks, or other mobile units such as boats, barges, etc., will be connected with the general telephone system so that a subscriber to the general two-way mobile service can talk from an equipped vehicle to any one of the millions of telephones served directly by, or connected with, the Bell companies. Likewise, the occupant of an equipped vehicle can be called from one of the millions of telephones.

In general, here's how mobile radiotelephone service is expected to work in cities:

Calls to and from motor vehicles will be handled by special operators. The conversation will travel part of the way by telephone wire and part

of the way by radio. If a caller at his desk wants to talk to the occupant of an automobile, he dials or asks for the vehicular operator. He gives her the call number or designation of the vehicle. She sends out a signal on the proper radio channel by dialing the code number assigned to that particular vehicle. An audible or visual signal indicates to the car occupant that he is wanted. He picks up the dashboard telephone, and the conversation starts. Under his fingers as he holds the telephone handset is a "push-to-talk" button which permits him to switch from receiving to sending.

The operator of a mobile unit can originate calls merely by picking up his telephone and pushing the "talk" button. This signals the vehicular operator and she "comes in on the line" He gives her the telephone number he wants and the call goes through.

In large metropolitan centers it is probable that a number of fixed receiving stations will be employed, located throughout the area so that the relatively low-powered mobile radio sets will be within range at all times. The receiver nearest to the mobile unit will pick up the voice signals and send them on their way by telephone wire. It is planned also to have more than one transmitter in order to give full coverage.

Three classes of mobile service are contemplated:

1. A general two-way telephone service between any telephone and any mobile unit, with a three-minute initial period and the usual one-minute overtime period.

2. A special two-way dispatch service between a telephone at the dispatching office and specified mobile units. A direct line from the dispatcher to the telephone central office would be furnished as part of this service. A one-minute initial period and the usual one-minute overtime period would probably apply here.

3. A one-way signaling service to mobile units, to notify the operator of the unit that he should comply with some pre-arranged instruction, such as calling his office from the nearest public telephone.

Another type of mobile radiotelephone service which will be tried will furnish two-way voice communications to motor vehicles operating on intercity highways and to boats on adjacent waterways. This service would require transmitting and receiving stations along the highways to be served. The mobile units would be equipped for receiving and sending, and with signaling equipment similar to that to be used for urban service.

CHAPTER EIGHTEEN

MAINTENANCE AND REPAIR

1 General Information

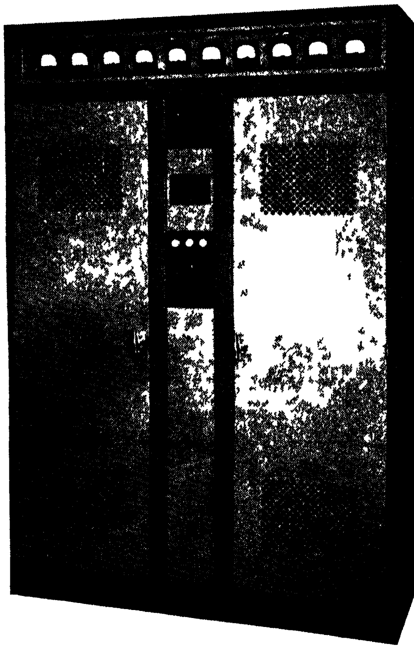
It is impossible to enumerate everything that might go wrong in radio or electronic equipment. Manufacturers sometimes indicate in their instruction manuals the troubles that may result from omitting parts or substituting parts of wrong value or type. Such information is valuable but does not fully duplicate the actual experiences generally encountered by maintenance personnel in the field.

For example, a two-way radio station might have a total of 20 tubes. These tubes might have an average of 5 component parts or elements each, such as filament, cathode, anode, control grid, screen grid. The number of troubles that the 20 tubes alone could develop if faulty is not 20 tubes times 5 elements, or a total of 100. Instead, it is 20 tubes multiplied to the fifth power, or a total of 3,200,000. In addition, such an equipment might have about 300 resistor, capacitor, inductance, socket, terminal, and junction wiring connections. Multiplying 3,200,000 by 300 results in a total of about one billion points of possible malperformance.

This may seem like a hopeless number of troubles to ferret out if anything should go wrong. However, there are never that number or anything near that number of troubles which cause actual inoperation. This number merely represents the causes of normal, abnormal, or subnormal performance. Ordinarily all three of these conditions exist among the radio components, and they average up to what is considered normal performance. Occasionally one proudly boasts that a certain equipment or system gives phenomenal results. This may mean that maximum or abnormal conditions prevail among the billion details. Everything "clicks" and is additive throughout the circuit. Another person reports poor results, which means that more things are subtractive than additive.

While the number of reasons for possible inoperation seem to be innumerable, a study of any radio, electronic, or electrical circuit, other than the tubes, is found never to comprise more than three basic components: inductance, resistance, and capacitance. What makes the equip-

ment appear to be complex are the number, size, manner, and method of connection of these inductances, resistances, condensers, and tubes. If maintenance personnel will always remember what these four things basically do, little more than the instruction book, part checking or substitution, and reasonably good judgment is required to cope with any maintenance problem. If a record is kept of all the troubles encountered by symptom and remedy, it does not take long to build up a list which will begin to repeat itself. Thereafter it becomes a matter of minutes to remedy the great majority of troubles.



Front view of 100-watt medium-frequency transmitter with access doors closed. Harvey-Wells I T-100 master station of the Maine State Police The ten meters shown here are equivalent to thirty-five different meters, because of switching provisions. (Courtesy Harvey-Wells Communications, Inc)

2 Analysis of Troubles

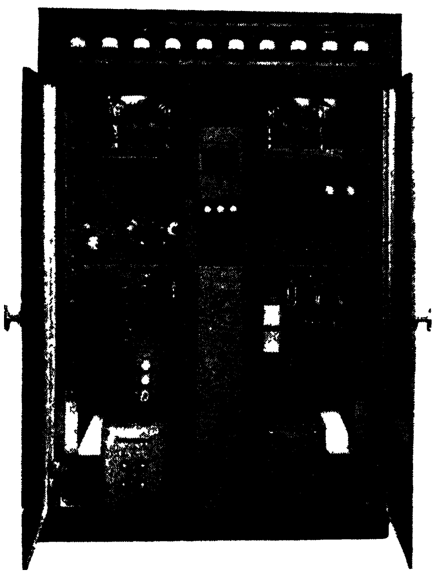
In analyzing the troubles that may be encountered in two-way radio equipment, they fall into three principal categories:

Safety Features. These include fuses, relays, interlocks, thermostats, circuit breakers, indicating instruments, and the like. While these safety features protect the equipment and personnel, they have little or nothing to do with the normal operation of the equipment. They cause inoperation if faulty merely because they are in series with the circuits Ordinarily, if bridged or shorted out, the circuit will continue to function so long as their malfunctioning is not the result of a short circuit, overload, or poor connections.

A fuse may blow out due to a sudden surge or change in the voltage or by the inadvertent placement of conducting metal, causing a live circuit to ground or short out In cold weather or where rotating machinery is not adequately lubricated and free to move with normal torque, a fuse may blow as the rotating part tries to overcome the higher initial torque of starting and tends to draw more current. Fuses sometimes are not ideally selected, being of a size based more on the normal operating load than on the higher starting load. In that case, they are much more

apt to blow out when an equipment is started up from a cold condition. Fuses sometimes are not properly seated, or they loosen in the fuse clips with time, or the wiring to the fuse terminal may loosen, with the result that the wire wanders to make contact with ground or another connection. Careful attention to these details in the design and subsequent installation or reinstallation of the equipment will avoid these situations.

Relays may not close circuits because of too much tension when they are new, or because the battery voltage becomes too low at times. When the equipment gets older, the relay spring tension decreases until finally it may fail to open up the relay contacts when it is supposed to do so. Sometimes the moving relay arm gets out of alignment, and the contacts do not come together properly. Relay contacts also develop glazed surfaces or dirty surfaces, so that when they come together they fail to make electrical contact and circuit continuity. The glaze or dirt then acts as an insulator even though the contacts appear to be in contact. Sometimes, due to excessive sparking, relay contacts will not break apart when the relay coil is de-energized because of pitting or rough contact surfaces. Glazed or dirty contacts should be cleaned or filed down with a fine file. Alcohol or other suitable solvent will remove the glaze. Pitted or rough contact surfaces should be filed and smoothed down. Relay contact arms should be checked for alignment to make sure that the entire contact surfaces of both the moving arm and the fixed contacts line up perfectly rather than partially with overlap.



Front view of Harvey-Wells FT-1000 medium frequency transmitter used by Maine State Police, with access doors open to show accessibility of tubes for test or replacement. Every part is fully visible and accessible. A circulating blower on each side ventilates the compartments. Transformers and chokes are oversize to operate cool with adequate safety factor. (Courtesy Harvey-Wells Communications, Inc.)

Interlocks are equivalent to switches which break the input power circuit when a unit is removed from its case and restore the circuit when returned to the case. If the unit is not fully back in place and secured with binding posts, it may not sufficiently or adequately engage, so that nothing happens. If the unit is to be operated out of the case for any

reason, such as during a bench overhaul, the interlocks must be shorted out to close the circuit. Sometimes foreign material, misshaped prongs, or a ground may exist to cause the circuit to be open or closed when the opposite should be the case.

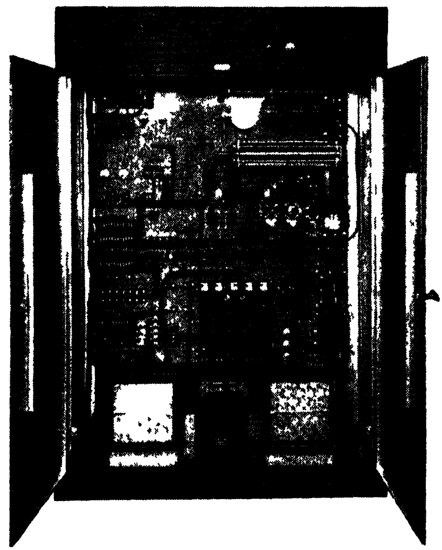
Thermostats have contacts that make and break circuits. It is important that the temperature in the equipment be held within narrow limits, so that the frequency of operation will not exceed the tolerance authorized by the Federal Communications Commission or the circuit design requirements. If the thermostat is maintaining the correct temperature and consequently the frequency in the transmitter unit, let us say, while failing to do so in the receiver unit, then one may be out of tune with respect to the other, so that ideal communication may not be possible. Thermostats are only used on frequencies where closer tolerances than normally exist happen to be necessary.

Quartz crystals to maintain transmitter or receiver on correct resonant frequency may fail to oscillate, making the equipment erratic or impossible to tune. This may be caused by change in tension within the crystal holder or by dirt, small as it may be. The entire crystal and holder should ordinarily be replaced and sent back to the manufacturer who usually guarantees it so long as the seal is not broken. However, this may not be convenient, particularly if no spare is available at the moment. The solution then is to break the holder seal, carefully remove the crystal, and examine it for fracture or flaw. Then wash it carefully in alcohol or carbon tetrachloride, check the contact tension, and replace it in the holder. This will usually correct the trouble. The crystal itself should not be directly touched by human hands, as enough foreign matter can be transferred to cause the crystal to function unsatisfactorily, even though not perceptible to the human eye. In washing or touching the crystal do not use any abrasive so as to change its thickness or uniformity, as that will change its frequency. If necessary, a crystal may be made smaller in area but not in thickness. Smaller area means that it will handle less power. Reduced thickness means that it will only function thereafter on a higher frequency.

Rotating or Switching Parts. Anything that moves or turns or depends on a sliding contact must of necessity be subject to wear from use and eventually require replacement. A switch will eventually get to the point where it makes poor or intermittent contact, as the tension decreases and the contacts get dirty or wear unevenly. A sliding type of variable resistor, volume control, or similar part will eventually loosen and make intermittent contact. This manifests itself by loud scratching, getting weak at times when it should be getting louder, or behaving in other erratic ways. A valuable part is worth overhauling by correcting the

sliding arm tension and cleaning the surfaces. An inexpensive part is usually more dependable if replaced.

Vacuum Tubes. Tubes have various life periods depending on their functions and circuit voltages, also on how heavily or how lightly each tube is driven. An amateur may take a tube rated continuous service at 10 watts and drive it at 100 watts. Event hough it develops a red plate during use, the small amount of service and the intermittency of the service permits this to get by. A broadcasting station operating in constant and continuous service would have to run that tube possibly at 5 watts in order to get a long tube life. Two-way radio transmission is usually for brief intermittent periods, so that it is safe to operate a tube at the normal rating and even slightly beyond with considerable tube life expectancy.



Rear view with rear doors open of Harvey-Wells FT-1000 medium-frequency transmitter as used by Maine State Police at WBNV, Augusta, Maine. Every part is easy to view and check. The blowers, shown in the front view, are connected to the air filters shown in the lower part of this photograph, to prevent the formation of dust on the parts (Courtesy Harvey-Wells Communications, Inc)

3 Typical Troubles Encountered in Operation

The following troubles were encountered in about fifty two-way radio systems built or supervised for municipal, state, and federal agencies during the past ten years and in connection with radio repair service with the armed forces during World War II.

1. Swapping units with a vehicle which has its storage battery connected positive-to-ground rather than negative-to-ground, or vice versa. The dynamotor leads then have to be reversed, and/or the vibrator reversed in its sockets or its leads reversed.

2. Equipment inoperative because the technician put the wrong tube back in a particular socket or put several tubes back in wrong sockets.

3. Receiver inoperative. Vibrator was reversed in putting it back, or wrong-type vibrator was installed, or vibrator contacts within the case were sticking or stuck, requiring replacement.

4. Equipment inoperative because, unknown to the vehicle operator, an equipment unit has been left behind when removed. This might be a transmitter, receiver, loudspeaker, or microphone.

5. Antenna plug left off the equipment and not plugged back when the set was reinstalled.

6. Equipment out of adjustment due to tampering or mishap.

7. Tubes unable to operate at the frequency required, although testing O.K. in a tube tester. In one extreme case, four different tubes had to be tried before a good one was found. Defective tubes should be sent back for free replacement, and the manufacturer or the dealer should be changed if there are indications that rejects or tubes suitable only for lower frequency operation are being supplied.

8. Erratic tubes caused by using tubes of different manufacturers in the same equipment. This is seldom serious, as interchanges of good tube brands are ordinarily permissible.

9. Poor tube-socket prong tensions, or prongs too close to other circuit connections which may short against it.

10. Shorting caused by too much surplus connection lead or a piece of solder hanging over from a lug or prong.

11. Failure of a mechanical or electrical connection to hold. Parts should be held together mechanically and electrically both by wrapping and soldering each connection, so that if one fails the other will maintain circuit continuity.

12. Broken antenna.

13. Loose hardware.

14. Too much throw or resilience in the shock mounts or absorbers, resulting in excessive movement of connecting cables so as to produce wear.

15. Inadequate shock mounting and absorption over hard terrain, causing parts to get loose, touch others, or change their dimensional and distance characteristics with respect to everything else in the equipment.

16. Break in wiring underneath insulation, making it difficult to find, particularly if some continuity remains. This is common in the microphone, usually within two or three inches from where the wire enters the handle of a hand microphone in a mobile unit, and may be caused by frequent handling of the microphone in connection with use.

17. Faulty toggle switches.

18. Stuck relays caused by pitting and uneven wear.

19. Open relays caused by glazed or dirty contacts.

20. Improper relay-spring tension adjustment.

21. Insufficient voltage from battery caused by corroded cable, dirty battery lug, poor insulation, or chafed insulation with some high-resistance leakage to ground.

22. Grid caps off tubes.

23. Bad quartz crystal which may be dirty, chipped, changed in frequency, or have too much or too little surface contact tension.

24. Detuned equipment which cannot be readily brought back to a stable condition. Usually encountered when no alignment equipment or aids are available and too many stages are tuned or detuned at one time. Start tuning the first stage, *not a subsequent stage*, and progressively tune the succeeding stages; otherwise, the odds are approximately 180 to 1 of hitting it right in each stage. In one stage, the odds will be 180 to 1; in two stages, 180 × 180 to 1; in three stages, 180 × 180 × 180 to 1. If no other means is available, tune up in conjunction with some station of known frequency in close proximity, such as a mobile unit providing the test alignment signal.

25. Faulty modulation. Too sensitive a microphone or too loud or too close

a voice with respect to the microphone may cause distortion and unintelligibility. Too insensitive a microphone or too weak or too distant a voice may cause the intelligence to be too weak and seem too far in the background despite an otherwise powerful radio carrier.

26. Unable load antenna. Coaxial cable may be shorted, or the outer conductor is floating rather than grounded to equipment cabinet and to vehicle body at the antenna.

27. Loose power plugs or poor or even no contact to one of the cable connections. Also improper seating of multicontact plug connections when returning chassis into equipment cabinet or undue force used to get it back in.

28. Breaking off the key or a prong of a tube when removing the tube or replacing it in the tube socket. Tubes should be inserted and removed vertically.

29. Defective parts, such as a condenser shorting or opening up, or a resistor changing its value.

30. No meter indication. Stuck meter, damaged meter, damaged or loose meter shunt, or loose lug connection.

31. Poor connection caused by excessive rosin and little solder holding the wire to a lug or prong, or by the use of cold solder which did not properly flow at the time of soldering.

32. Poor loading of antenna, causing poor reception or transmission where air dielectric coaxial cable is used. May be due to condensation and shorting of the insulated inner spacer beads used to hold inner conductor in place. Check by disconnecting coaxial cable at each end (inner conductor only) and try to measure infinity resistance between inner and outer conductor at either end of the cable. If there is a measurable resistance, or none, then it indicates partial or total leakage short between the inner and outer conductor of the coaxial cable. Even solid dielectric may justify similar checking, as a short may develop at a termination due to a loose strand or solder.

33. If trouble lies in a certain cable or wiring, look first at terminations or joints as the likely source. Only rarely will it be along the cable run itself.

34. Antenna grounded to body of car where it enters or is attached. Check insulation, unless the antenna is designed to work quarter-wave against ground.

35. Certain antennas, such as the coaxial radial type using counterpoise rods, will measure a short between the inner and outer conductors of a coaxial cable. For test of the cable in such an installation, the inner conductor must be first disconnected at the antenna.

36. Loudspeaker trouble, such as a damaged cone, cone detached from voice coil, or open voice coil.

37. Tuning jacks not making circuit contact or not plugging in correctly. Some plugs may not enter far enough or may go in too far, due to inadequate shimming of the jack to provide proper insertion distance for the phone plug.

38. Equipment wet or immersed. If by fresh water, dry thoroughly and blow air through. The toggle switches may become shorted and irreparably damaged because of enclosure and require replacement. Check all parts to see if their values have changed. If immersed in salt water, immediately immerse the equipment in fresh water several times and wash off as much as possible the effects of the salt water. If this is not done or is delayed, the equipment becomes largely worthless, as corrosion will commence, and various troubles will develop from time to time to make the equipment undependable thereafter. In any case, the toggle switches and probably the meter windings will be useless.

39. Equipment covered with dust. Blow the loose dust out with compressed air. Dust that does not blow out should be carefully wiped out. Corrosion or inaccessible dirt should be wiped with a pipe cleaner or other suitable aid immersed in alcohol, carbon tetrachloride, or other solvent.

40. Poor ground or circuit contact. Check all attachments of metal grounded cases to point of attachment, since it may form ground return. If necessary, scrape paint away between surfaces to make good contact.

41. Equipment goes out of tune. Tune off resonance slightly on the side where the meter reading falls off slowly, not the side where it falls off more abruptly.

42. Clean antenna insulators whenever necessary.

For additional information, read specific advice in the various chapters of this book describing equipments. In addition, technicians will get considerable information from manufacturer's instruction books, particularly if the equipment has been in production a few years.

4 Tools, Parts, and Test Equipment

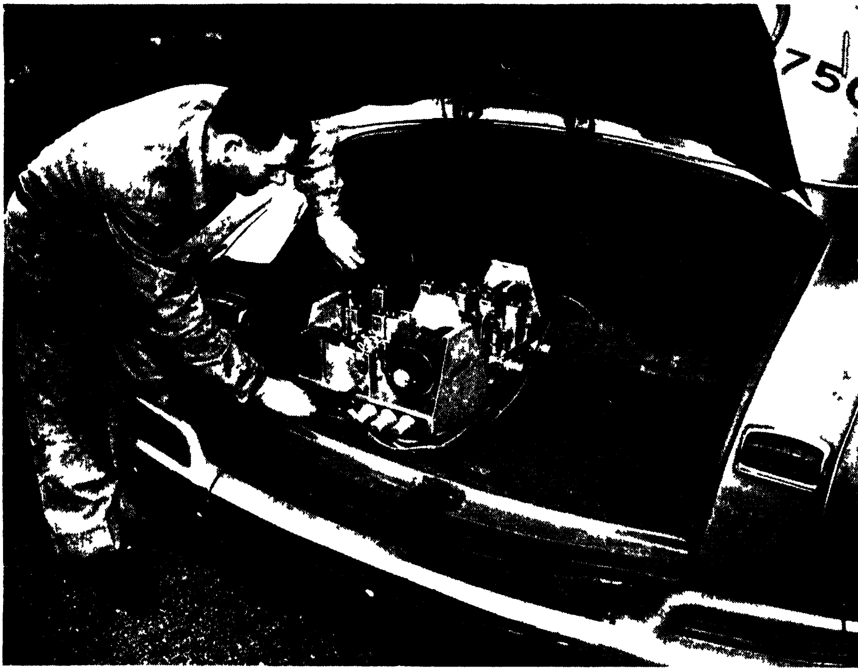
To cope with all conditions of establishing and maintaining a radio system, provisions should be made for the following routine matters:

1. Initial installation of fixed and mobile stations.
2. Reinstallation of mobile stations. The radio equipment may be economical and still efficient to use for a period of ten years. On the other hand, the plane or motor vehicle may have a life or be traded in for a new vehicle as frequently as once a year.
3. Normal replacement of radio vacuum tubes.
4. Replacement or repair of parts that move or get disturbed in the course of tuning or operating the equipment.
5. Salvaging and rebuilding equipment damaged as a result of vehicle collisions.
6. Periodic checking and overhaul of all equipment for wear, dust, corrosion, oxidation, condensation, or rust.
7. Frequency checking or correction.

An extensive system will have three different outfitting considerations.

Headquarters Maintenance Depot. In the largest systems, the headquarters depot or laboratory may have to provide for nationwide maintenance, and it should be exceptionally well stocked and equipped. It should be centrally located and so organized that personnel, parts, and equipment can be conveniently sent to any part of the system as required.

Field Maintenance Depots. These are located in a room or space of a barracks, railroad station, airport, or bus terminal, depending on the system involved. They should have secondary test equipments—all but the heaviest tools maintained at the main laboratory —and a stock of all parts that might have to be replaced. In addition, a complete spare mobile unit should be provided. Some systems try to have on hand, ready for replacement, one complete spare equipment for every ten in service. When



Trouble-shooting two-way mobile equipment (Courtesy Galvin Manufacturing Co.)

equipment becomes defective or inoperative, an exchange is made rather than an attempt to make immediate repairs while the vehicle stands by or goes without.

A technician, except in the rarest permissible situations, will not be performing his duty in keeping with the traditions of his profession if he leaves any fixed or mobile station out of service because he has already done a normal day's work. So long as he has not reached the stage of complete exhaustion, he should carry on and put the station back into at least temporary service. The normal operation of all mobile and fixed stations is more important than the individual. Technicians and engineers have voluntarily established this rule for themselves. It is hoped that newcomers will do likewise, so that two-way radio will continue to be held in the highest regard as a dependable and reliable medium.

Traveling Technician. While most mobile units can travel to a maintenance depot, the fixed stations cannot. The technician must go to them. He may travel in an automobile or small service truck, in which case he can be well equipped. On the other hand, he may travel by common carrier and have a minimum number of compact lightweight items with him. The minimum may be a soldering iron, solder, tape, volt-ohm-

milliammeter (midget type), one of each type tube used, pliers, screw driver, wrench, some hookup wire. A man with practical experience can do surprisingly well with that minimum.

In the latter case, a technician might have to buy an item locally or improvise. A local radio dealer or radio amateur may be able to help him out. By carrying some basic-sized resistors and condensers, he can build them up to desired values by hooking them up in various series or parallel combinations, if such parts are the source of trouble in the defective equipment. The more important fixed stations may have a few parts on hand, such as a set of spare tubes. If checking equipment is lacking, substitution of spare parts or tubes may be necessary.

From the following lists of tools, parts, and test equipment, the average radio system can build up the facilities it requires according to the scope of its operations. The common tendency to overbuy and over-equip at the time of the initial appropriation and then to underbuy or have no appropriation thereafter should be discouraged. It is better to buy the minimum and add to it from time to time, as experience and conditions encountered for a specific system and application may indicate.

Tools and Parts

Electric drill
Spare drills
Alignment tools
Drill press
Small lathe
Soldering irons
Solder
Tape
Fuses
Screw drivers
Chassis holder
Pliers
Wire strippers
Hack saw and blades
Hole cutter
Hookup wire
Pilot-light bulbs
Small hardware: bolts, nuts, lock washers, grommets, lugs
Extension cord
Portable extension light
Flashlights
Electrical fittings, such as male and female cube tap for increasing outlet connections or plugging into a light socket
Electrician-type wrench set
Socket wrenches
Adjustable wrench
Pipe wrench
Lineman's belt
Pole-climbing equipment
Drafting set
Instruction books
Basic reference books
Tube manual
Radio catalogues
Trade magazine

Test Equipment

Tube tester
Volt-ohm-milliammeter
Storage battery tester
Dry battery tester
Microammeter 25-0-25 or 50-0-50 scales, unless included in other meter scales
AC and DC ammeters
- 0 to 1 ma.
- 1 to 10 ma.
- 0 to 100 ma.
- 0 to 500 ma.
- 0 to 10 amperes
- 0 to 50 amperes

Voltmeters AC and DC
- 0 to 3
- other values up to 5000 volts

Ohmmeters, electronic type

Ohmmeters, battery type, up to 10 megohms or more
Cathode-ray oscilloscope with 3-inch or 5-inch tube
Battery charger
Capacitance meter
Signal generator to reach all frequencies required
Wave meter for the specific frequencies of the system
Facilities for checking wave meter against primary standard, such as Station WWV of the Bureau of Standards

Miscellaneous Spares and Inventory

Adhesives
Meters
Coaxial cable
Coaxial cable clamps
Cable terminations
Wave guides and terminations
Tower-light bulbs
Ordinary light bulbs
Transmitting tubes
Receiving tubes
Test equipment tubes
Test equipment batteries
Storage batteries
Portable dry batteries
Wire, all types used: multiconductor, shielded, battery cable, coaxial cable, microphone cable, hookup wire
Extension connectors
Termination plugs
Phone plugs and jacks
Headphones
Microphones
Combination handsets
Pilot-light assemblies
Pilot-light bulbs
Pilot-light jewels: green, red, amber, white
Fixed resistors, all basic values
Variable resistors, all basic values
Potentiometers, all basic values
Fixed condensers, all basic values
Variable condensers, all basic values
Chokes and inductances as used
Coil forms
Replacement dials or knobs
Loudspeakers
Loudspeaker cones and voice coils
Equipment paint and finishing and refinishing materials
Lubricants or greases
Relays
Dynamotors
Vibrators
Sockets, all types used
Grid caps for small and large tubes
Quartz crystals of type used
Fuses
Tape
Gaskets
Graphite
Grommets
Antennas
Insulators of type used
Toggle and other switches used
Spare relay springs
Miscellaneous hardware
Polystyrene or other bulk insulation
Shim material
Washers
Shock mounts
Solvents
Tube shields
Tube clamps
Transformers of type used
Nitrogen gas, if used
Antenna guy wire, if used; turn buckles, insulators, etc.
License frames

Furniture

Equipment housing
Operating desk
Maintenance or test bench
Compartmentation or classified bins for all small and miscellaneous parts
Lockers to protect costly and delicate equipment
Tool rack with clamps to hold each tool where it can be found again
Typewriter and desk
Stationery
Maintenance forms
FCC license forms
Kardex or other record files
Records of all equipment and personnel licenses and their dates of expiration and renewal
Book and magazine rack to facilitate retaining and keeping accessible all reference data
Telephone
Incoming record book
Outgoing record book
Cost accounting and breakdown for the system and its units

5 Storage Battery Maintenance

When opportunity affords or as the radio load may require, storage batteries should be checked. An important radio system should have a spare battery on hand for replacement or exchange. The mobile station under normal conditions of service does not ideally cycle the battery; that is, it does not fully discharge or fully recharge the battery. Instead, it discharges as required and charges when the opportunity affords. Most mobile applications, such as railroad, aeronautical, marine, or motor vehicles, involve the use of storage batteries having erratic discharging and charging rates.

Generally speaking, a storage battery should not be discharged beyond its rated capacity. It should not be charged beyond its rated capacity, as buckling of the plates will result. It should not be charged or discharged with the electrolyte liquid below the top of the plates. Each cell should have ventilation, and the hole in each cap cover should not be plugged. The fumes emitted from each cell during charging are inflammable and even explosive if permitted to accumulate and remain in a closely confined space without ventilation. The more uniform and complete each charge and discharge of a battery, and the lower its discharge and charging rate, the longer life it will have.

The charging generator is often a cause of trouble that does not manifest itself until storage batteries begin to fail repeatedly in service. It may be brush trouble, dirty or rough commutator, sticking cut-out and cut-in relay contacts, or dirty terminals covered with grease or grime causing leakage to ground. The average battery, without special attention to these matters, will be overcharged by day in summer and overdischarged by night in winter. In an overdischarged battery in winter. the electrolyte will freeze and ruin the battery. This should be guarded against. If the battery is low and a substantial drain is required, such as for radio transmission, then the engine should be running to float the battery and supply power partially or wholly direct to the equipment. Although tubes can function less efficiently at reduced voltages, usually the equipment as a whole will not operate because the voltage may be too low to operate the circuit relays that close the various circuits. In emergencies where communication must be maintained with a nearly dead battery, it may be necessary to operate the relays manually for each transmission.

The following information developed for the Maine radio program may be of value to users of two-way radio facilities depending on storage battery power.

Discharging. High discharge rates are often confused with an overdischarged condition, resulting from too many ampere-hours being removed from the battery.

A properly designed storage battery can be discharged at any rate of current flow that it will deliver. The maximum discharge current is limited only by the size of the wire in the external circuit; the size of the connector posts or terminals; or the current-carrying capacity of the load. A cell may be actually short-circuited without buckling the plates. The number of ampere-hours that can be obtained from a battery is higher when the discharge rate is low or intermittent.

The terminal voltage drops faster on rapid discharge rates. Normal capacity rating is the number of ampere-hours obtainable under certain working conditions.

Batteries must never be left in a discharged condition for any length of time. In an emergency it will do the battery little or no harm to completely discharge it; but it must be recharged promptly before the lead sulphate becomes hardened.

The discharge of a battery must not be carried beyond the normal discharge condition. If this is done, permanent harm may result to the battery. The normal discharge condition is determined by a drop of 100 points in specific gravity from the normal charged condition; that is, a stationary battery would be discharged when the specific gravity dropped to 1.110.

Charging. The chemical action of the battery must be reversed from that of the discharged condition. This is done by forcing a direct current through the battery in the direction opposite to that of the discharge current flow. It is only possible to use direct current to charge batteries. If alternating current only is available, it must be converted to direct current by some rectifying means.

The voltage of the charging source must be slightly higher than that of the battery to be charged. About 2.5 volts per cell is the correct charging voltage.

During the early part of the charging period, the plates are able to give up acid at a rapid rate. When the charging is near completion, it is necessary to reduce the rate of charge; but this does not apply to a low rate of charge.

If too high a rate of charge is applied to the battery, only part of the current acts to charge it. The remaining portion decomposes the water in the electrolyte, forming hydrogen and oxygen. This results in gassing of the cells and a bubbling or boiling action caused by the escaping gas. The shedding of the active material is hastened by this bubbling action which knocks the softened material off the plates. The rate of charge that will cause gassing depends on the specific gravity, the temperature, and the state of charge of the battery. The temperature of the battery must be held below 110 degrees Fahrenheit and depends on the rate of charge.

It is often possible to keep batteries under light charge at all times. This is called a trickle charge. Due to local action, a battery will run down when not in use.

Routine Maintenance. The gases given off when batteries are on charge form a combination which will explode if ignited from any source. It is therefore very important to keep battery rooms well ventilated at all times.

If wrong polarity is observed in charging batteries, the chemical action will not be reversed and the batteries will become further run down. This may result in buckling of plates and the destruction of the battery.

Keep the level of the electrolyte so that it covers the plates. Distilled water should be used to replace water lost by evaporation, and to safeguard against metallic impurities in ordinary water. The acid does not evaporate and is only lost by spillage or leakage. Acid should not be added to the cell unless some has been lost. When mixing the electrolyte, the acid should be poured into the water—never the water into the acid. Never allow foreign matter of any type to get into the cells.

Keep the battery tops clean and dry at all times. Dirty battery tops will cause leakage between terminals and run down the battery. Keep the terminals and electrical connections clean and bright and free from corrosion Sometimes it is necessary to apply a coating of vaseline to the terminals to prevent corrosion.

Hot and freezing temperatures must be avoided. A discharged battery can freeze up, the exact freezing temperature depending on the gravity of the electrolyte solution. A battery has much less available energy at zero temperature than at normal temperature. Temperatures over 100 degrees can also damage the battery during charging.

6 Frequency Measuring and Monitoring

To conserve frequency spectrum and prevent interference by stations operating off their assigned frequency, the Federal Communications Commission has established rules that must be observed with respect to transmissions.

Even were this not mandatory, it would be necessary in order to assure that transmitters and receivers were tuned to the same frequency; otherwise, two-way radio communication would be difficult to maintain. It does not take a very great percentage of frequency deviation of either the transmitter or receiver to cut down vastly the signal strength and the communication range.

When the transmitter is off frequency for an amount exceeding the band width of the receiver, then communication becomes impossible altogether. Low-powered inexpensive equipment operating on the correct

frequency is many times more efficient in both signal strength and range than high-powered costlier equipment which drifts off the optimum point even a small amount, so far as receiving conditions are concerned at the distant point.

This state of affairs is increasingly true on the lower frequencies, becoming less marked (in terms of kilocycles) in the higher frequencies, until on super high frequencies a receiver will respond over a range of several megacycles. However, that is true only because a small change in wave length represents a great amount of frequency in that portion of the radio spectrum. It is still necessary to guard against drifting too much in wave length.

It is important in any case to have accurate and dependable means of knowing that a station is on the correct frequency or as close to it as necessary for a receiver to pick up the transmitter. It is also necessary to have means of knowing and controlling the transmitting frequency, so that it will not knowingly and avoidably interfere with other radio transmissions on adjacent frequency channels. On the standard broadcast band, the frequency is maintained plus or minus 50 cycles ($1/20$ of a kilocycle). For example, if the broadcasting station is on 1000 kilocycles, this means that the frequency accuracy is maintained 1 part in twenty thousand. On the very-high-frequency band, an accuracy as low as .01 per cent is required by the FCC. This means that on a frequency of 40,000 kilocycles (40 megacycles), the frequency must not fluctuate more than 4 kilocycles in either direction; that is, the frequency must stay within the tolerable limits of 39,996 and 40,004 kilocycles. This is only possible with crystal control of the frequency and minimum temperature fluctuation.

Causes of Frequency Fluctuation. The fixed station is usually inside a building having a fairly uniform temperature, but in the case of remote control stations, this may not be true. In the case of a mobile station, the equipment may have to operate in the course of a year in temperatures varying between 100 degrees above and 50 degrees below zero Fahrenheit. Some frequency deviation is inevitable and too selective a receiver is not recommended.

A change in voltage definitely changes the frequency, since it changes the circuit-constant behavior. Good voltage regulation therefore improves frequency stability.

Movement of the equipment, such as a swaying antenna, and vibration in a moving vehicle changes the placement with respect to the earth and to objects in the proximity of the equipment, and this also causes frequency fluctuation.

The following provisions will minimize or keep within tolerable limits any frequency fluctuation that radio equipment may otherwise develop.

1. Keep the equipment in a compartment where a uniform or reasonably uniform temperature is maintained, if that is convenient to provide.

2. Provide automatic thermostat inside the equipment, particularly in the frequency determining or controlling stage (such as in the crystal holder or in the oscillator section), that will cut in or out a heater and/or a ventilating blower.

3. Keep the tubes lighted at all times. They will maintain a stable temperature that will not fluctuate.

4. Turn on the tube filaments a considerable period before using the equipment, so that a stable temperature and stable frequency will be reached before communication commences.

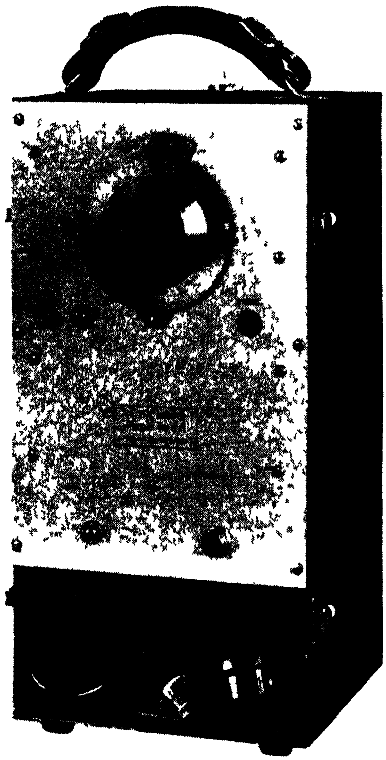
5. Utilize special low-drift oscillating crystals made of quartz or other special material, such as Rochelle salt or tourmaline. Other types may still be under development or projected during the future. Such crystals will only permit a circuit to oscillate a single frequency, dependent on the thickness of the crystal slab. The thinner the slab, the higher the frequency. The slight crystal drift will be further reduced by keeping its temperature controlled with a thermostat and heating element. Even inexpensive crystals can maintain an accuracy of 1 cycle in a million per degree of centigrade temperature variation.

As equipment is used with lower power in higher and higher frequency spectrum congestion and interference with distant radio services becomes much less probable, less elaborate provisions become necessary. Also the radio profession has had less time to develop frequency stabilizing equipment there. The FCC co-operates by permitting more tolerance in the case of low-powered mobile applications, even on the lower frequencies, because of their reduced coverage as compared with high-powered fixed stations. Instead of .01 per cent it may be as high as .05 per cent. In the case of microwaves, the FCC has permitted fluctuations of several megacycles because of technical considerations, local coverage, and adequate frequency spectrum.

In any case, it is necessary, whether regulations require it or not, that the receiving point be in tune with the transmitting point. This can be effectively accomplished by equipping the receiver with an automatic frequency control (AFC) circuit. This operates similarly to the discriminator in an FM equipment. As the transmitting frequency changes within small limits, the receiver AFC circuit develops a positive or negative change in voltage with respect to a mean frequency (that is, the correct frequency). This voltage change causes the receiver correspondingly to change its frequency response, since voltage change causes frequency change for the same parts and circuits. The receiver therefore faithfully tracks the transmitting signal and remains ideally responsive to it at all times.

Monitoring and Measuring Equipment. For medium, high, and very high frequencies (that is, frequencies between 1600 kilocycles and 42,000 kilocycles in the case of two-way radio), equipment is available that is

widely used by police, fire, forestry, and similar services. In this region, the FCC has set forth frequency provisions that require special equipment to check the frequency of every transmitter and to monitor the transmissions so far as may be necessary or desirable to assure proper functioning of the equipment in accordance with the license authorization.



Portable Link AC monitor, type 230-B, frequency range 30 to 40 megacycles

Whereas commercial stations may use frequency control and monitoring facilities that are exceedingly complex and costly, two-way radio systems ordinarily cannot afford such excessive attention nor is it wise to incur such expense, as it might become an important part of the total cost of the system. To take care of two-way systems, several types of reasonably simple and inexpensive equipments have been developed by manufacturers. Any one of these costs substantially less than one mobile station. Such facilities can perform the following functions:

1. Check the exact frequency of the transmitter.
2. Feed a signal into a receiver of a precise frequency for tuning purposes.
3. Check the frequency of a crystal used in a transmitter.
4. Check the amount of frequency deviation during FM transmissions.
5. Listen to the actual signal as it is being transmitted to determine its quality as it would be picked up at a receiving point.

On frequencies much higher in the spectrum, crystal control becomes difficult to provide without much frequency multiplication. Simpler even if somewhat cruder means are utilized. This includes a simple lecher wire system in which the current or the voltage nodes are checked by using a light bulb to get a current indication, or a neon bulb to get a voltage indication, as it is slid along the wire every half-wave length. By measuring the distance between two half-wave-length points, the wave length and frequency can be directly computed.

Three popular types of frequency measuring and monitoring equip-

ment used by stations, particularly prewar, are the Link, Browning, and Doolittle models described here. There are also other types more or less elaborate than these, and new improved types are undoubtedly under development, particularly for higher frequencies.

Link Crystal Monitor. Link crystal monitors are designed for accurately checking the frequencies of transmitters and receivers. They are specifically intended to permit full compliance with requirements of the Federal Communications Commission and are used (1) to check frequency of crystal-controlled transmitters; (2) to tune master oscillator-controlled transmitters to a predetermined frequency; (3) to check frequency deviation from a predetermined frequency; (4) as a variable or fixed frequency signal generator for testing and aligning receivers; (5) as a monitor receiver to check the quality of transmission.

These monitors incorporate two oscillators, one being an aperiodic crystal and the other a stable variable oscillator controlled by a micrometer dial located on the front panel. The crystal oscillator circuit requires no tuning regardless of the frequency of the crystal used, and the frequency is not affected by wide changes in circuit constants. The crystal is ground to a tolerance of .005 per cent of the desired operating frequency. The variable oscillator is accurately calibrated, the calibration curve being attached to the inside of the front cover. By turning on both oscillators at the same time and tuning the variable oscillator to the crystal frequency, the variable oscillator may be recalibrated at any time. A grid leak detector and audio amplifier are included to permit aural monitoring. Clips on the inside of the cover hold a rod antenna which is plugged into the top of the case. A leather carrying handle permits ready portability, the metal cover fully protecting the instrument from damage.

Type 230-B is normally furnished for one frequency in its specified range, with a variable range of 1 megacycle. (For example· operating frequency 33.1 megacycles; variable range 32.6 to 33.6 megacycles; crystal control point at 33.1 megacycles plus or minus .005 per cent.) This monitor can also be furnished for two frequencies; for example, one in the UHF band and one in the intermediate-frequency band. These monitors are available in standard relay rack mounting or the portable case illustrated.

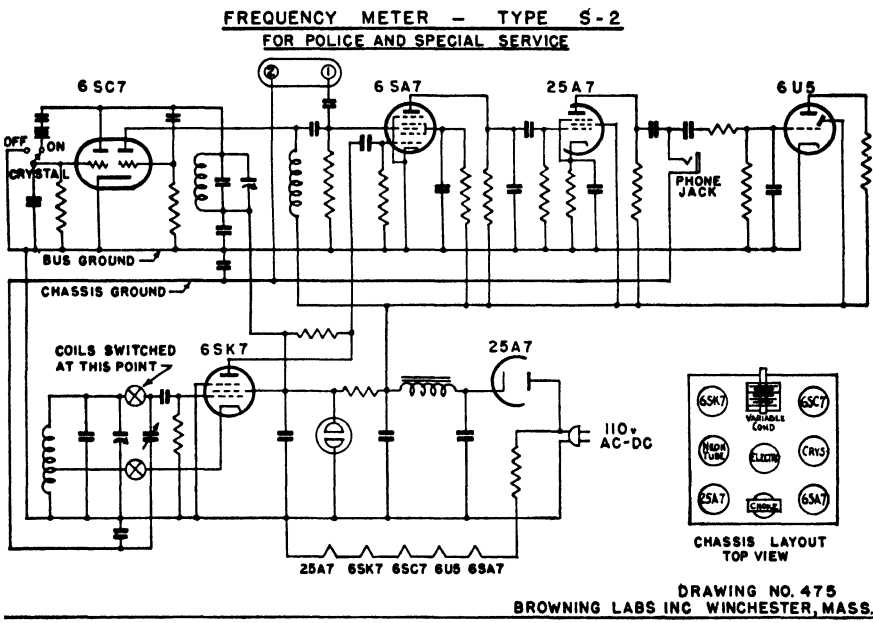
Type 230-A is the same as 230-B except that the variable oscillator covers the full 10-megacycle range, thus yielding somewhat less accuracy of scale (frequency) reading. Both types are extensively used for all emergency radio work, such as police, fire, public utility, and the like.

Browning Frequency Monitor. The Browning Type S-2 frequency monitor is designed for accurately checking frequencies in any five bands (25 to 500 kilocycles wide depending on location in spectrum) from 1.5 to 60 megacycles. A 100-kilocycle crystal is used as a secondary standard. Its frequency may be checked readily against the National Bureau of Standards Station WWV or any reliable broadcast station operating on a multiple of 100 kilocycles.

Stable electron-coupled oscillators are used to cover a band of frequencies from 25 to 500 kilocycles wide. The required frequencies are included in these narrow bands. A 5½-inch vernier-drive dial is attached to the condenser controlling the variable oscillator, and an accurate calibration of this dial given. The circuit is so designed that at least two points on any band may be checked against the 100-kilocycle crystal oscillator. Slight adjustments of the variable oscillator by means of a front panel control are made when necessary, so that the calibra-

tion of the variable oscillator is at all times reliable. The specified frequencies are clearly indicated on the calibration curve and their dial settings given.

To facilitate zero beat adjustments, a tuning eye is employed. When exact zero beat is obtained, the eye opens. Either side of zero beat, the eye flutters at the beat note rate. A phone jack is provided so that zero beat may be indicated aurally as well as visually. The tuning eye is employed both in checking the variable oscillator against the 100-kilocycle crystal and the transmitter against the variable oscillator. It may be used also to check transmitter frequency deviation. Checks on the transmitter frequency may be made very rapidly, the average time required being less than a minute.



The accuracy of the meter depends primarily on the accuracy with which the dial may be read. It is this reading accuracy requirement which determines the band width employed at any point in the spectrum. There are 200 divisions on the main $5\frac{1}{2}$-inch tuning dial. Reading to one-half of one division is entirely feasible. At 1500 kilocycles this provides a reading accuracy of .004 per cent with a band spread of 25 kilocycles. The same accuracy at 30 megacycles is obtained with a band spread of 500 kilocycles. The calibration curve is drawn in the laboratory by means of a frequency standard whose accuracy is better than 5 parts in 5 million and which allows check points every 10 kilocycles.

The highest order of stability is obtained by voltage regulation. Line voltage changes of 10 per cent have a negligible effect.

With a room temperature change of 10 degrees Fahrenheit either side of the temperature at which the crystal is accurately set, the resulting frequency error in crystal frequency will be .002 per cent. The time taken to reach operating temperature is about one hour. Means are provided for changing the crystal frequency

slightly so that this frequency may be at any time adjusted to at least 50 parts in 5,000,000 against the National Bureau of Standards Station WWV by the zero beat method.

Doolittle Frequency Monitor. The Doolittle frequency monitor Model FD-9 consists of a converter fed by a crystal oscillator and the incoming signal whose output passes through a broad-band IF amplifier and limiter stage to a discriminator transformer and associated diodes. The AC and DC voltages across the load resistors are used to operate the modulation meter, the peak flasher circuit, and the center frequency deviation meter.

The main function is to indicate the actual frequency swing of the carrier in kilocycles of maximum excursion for sine wave audio modulation of the FM transmitter. This is indicated at the right on the monitor. At the left is indicated whether this modulation is symmetrical about the nominal carrier frequency. The center indicates carrier level and the flashing indicator below indicates instantaneous overmodulation. The point at which such indication is desired is set by the control directly below the flasher.

The FD-9 is coupled to a final amplifier of an FM transmitter by means of a pickup coil and a twisted or shielded pair. It is also possible to measure mobile units with an antenna pickup, provided they are between 50 and 100 feet from the monitor.

The frequency range of the Doolittle monitor is 30 to 50 megacycles. The accuracy of the carrier frequency measurement is .005 per cent. This accuracy is recognized by the FCC as being adequate. The stability of the monitor frequency is 2 cycles/mc/°C. The center frequency deviation range is plus or minus 15 kilocycles. The maximum excursion is 20 kilocycles plus or minus. The accuracy of the center frequency deviation meter is .01 per cent at 20°C corrected. This information supplements that given by the carrier frequency measurement, but is not actually required by the FCC. The accuracy of the indicator is 2 per cent of scale or ½ kilocycle, whichever is greater.

Note: Frequency-measuring equipment of the types described above has recently or currently been subject to redesign. This has been made necessary by the extension of the very high frequency band allocations for highway and railway applications. Whereas pre-war frequency-measuring equipment usually stopped at 42 megacycles, the new equipment will accommodate all the bands up to 162 megacycles and beyond. Precision equipment for frequencies above 200 megacycles is also under development but is of special types at this time.

7 Tuning and Adjustment

Tuning instructions vary with different equipments. Ordinarily, instruction manuals are available, and the manufacturer's recommendations should be observed. The details of tuning typical AM and FM equipment are given in Chapters Seven and Eight.

In general, the best way to tune in a signal is to have access to a signal on the frequency desired and then pick it up on a receiver. The signal may be obtained by having some station in the system transmit or keep its carrier on the air. To save doing this and not jam the air, a local signal generator with a calibrated output in terms of microvolts is used. An alternative is to use a frequency monitor wavemeter that is tuned to the

precise frequency. It is precise because it contains a crystal which is directly ground for the frequency or which has a multiple or harmonic that operates on the frequency.

Various indirect but nevertheless fairly effective methods are possible. A simple radio system usually considers its headquarters station as the standard frequency for the system. It is ordinarily the most efficient and stable equipment for the following reasons:

1. It is stationary and free from vibration.
2. It is housed and less subject to temperature variation.
3. The transmitter tubes are usually always lighted and have a stable operating temperature and frequency.
4. It has a primary power supply that is much more stable in voltage and frequency.
5. The antenna is fairly rigid and does not markedly change with respect to the earth either in distance or angle.

A mobile station in the field picks up the headquarters station and has its receiver ideally tuned to it. Then other mobile stations turn on their transmitters singly and are checked against that receiver.

If a receiver is tuned too close to another station in distance, it will not be truly tuned up. It is better to have one of the two stations mobile and to increase the distance and test one or more additional times. For example, a car may roughly tune its receiver in sight of headquarters. Then it travels about a mile and finds that the signal can be greatly increased by tuning. Then it may proceed 5 or more miles for a final tuneup. That tuneup will hold for any distance thereafter. The more powerful a transmitter and the higher its antenna, then the farther the other station should be removed to get a final optimum receiver adjustment.

Signal generators with calibrated outputs can assimilate such signals from a very strong signal, such as 10,000 microvolts initially, while the receiver is badly out of tune. Then reduce the input by steps while readjusting the receiver, until an input as low as 1 microvolt can be picked up with good intensity. This saves the time, travel, and expense of trying to do it in the field, which at best is an approximation although a very satisfactory one, since it is based on conditions and ranges encountered in actual practice. Some systems try to tune up in the field by moving a car away as far as possible. This is not very practicable, since nowadays equipment may have very substantial ranges, such as 50 to 100 miles airline, and it would take hours to travel that far with a vehicle and return.

For comparative field-strength measurements and maximum field-strength indications, the small system can build or purchase a simple field-intensity meter. This in effect is little more than a simple one- or two-tube receiver using a milliammeter or microammeter for indication

Test meter unit developed by Link Radio Corporation for adjusting the various stages of Link FM equipment (Courtesy Link Radio Corp.)

and a tuning condenser to tune the frequency range required. This condenser can be roughly calibrated. The fixed or mobile station is tuned for maximum field-intensity indication. Two-way radio between the station undergoing tune and the location of the meter, which is usually transported by a two-way radio-equipped car, provides communication between the two points for giving tuning instructions and reporting the results. This can be undertaken at distances of many miles. It can also be used for a radiation pattern check either near or remote from the antenna, so long as approximately uniform air-line distance is maintained in all directions.

Field readings taken too close to the antenna may be unduly influenced by local effects, such as a steel fence or adjacent structures. A nondirective antenna develops a figure-eight pattern tendency. It will be pronouncedly more effective for two quadrants and less effective in the alternate quadrants.

On higher frequencies, such as microwaves using parabolic reflectors or directive arrays, the signal will have most of its power beamed in a narrow cone. Except for minor lobes at reduced power and near the

antenna, nothing will be picked up except in the narrow cone of radiation. It is desirable that the minor lobes have minimum power while the main beam or cone of radiation has maximum intensity, unless other results are desired for some useful communication purpose.

A mistake made by less experienced radio maintenance personnel is to upset all the controls and try to retune a receiver or transmitter without a frequency generator or monitor. This can be done only with great care, and sometimes it is entirely impracticable to do so. For example, if there are 6 different condenser settings that must be tuned to the correct degree in a half revolution (in 180 degrees), since it takes 180 degrees of rotation to bring the condenser rotor plates completely in or out with respect to stator plates, the chance of tuning it up correctly would be 180 to the sixth power or over 35 trillion.

If a signal generator is lacking but some station is available for transmission, it is more sensible to throw nothing more out of adjustment than has already occurred and start progressively one stage at a time, using the loudest available signal, such as that obtained from a near-by unit. In extreme cases, a mobile station is placed immediately alongside the other station to be tuned up. Try to pick up some indication in the first stage tuning on the loudspeaker. Then proceed progressively stage by stage. Soon the signal will be too loud to work with. Move the other station farther away and continue. Then go back and retune all stages, working with a much weaker signal. If necessary, unhook the antenna on the other station and pick up a signal without or with very little antenna.

In the case of a transmitter using a crystal oscillator, it is suggested that all circuits be made inactive even if this necessitates removing tubes.

If the plate milliammeter reads too high, disconnect the load, and check again. If it does not go down, the circuit is out of tune. If it goes down without load and reads too high with load, then it is overloaded and must be tuned to a less loaded value. A well-tuned circuit will read the maximum grid input and minimum plate current possible to tune for, except where the grid current may develop to a higher value than needed for a loaded circuit. There must always be a pronounced and substantial dip in plate milliammeter reading when the antenna load is removed, and a corresponding increase when the antenna is connected to it as a load; otherwise, nothing is reaching the antenna. The antenna circuit must also be tuned so that it is feeding the antenna and getting the antenna to propagate, rather than the inner conductor of the transmission line en route from the equipment to the antenna. A further check is to get a report from mobile units in the field. If in the course of tuning subsequent circuits, a previously tuned circuit goes out of tune, and the meter tries to jump off scale, start over again with the last stage still normally tuned.

The function of each transmitting tube stage is either to increase the power or multiply the frequency, or to do both, depending on circuit design requirements.

Remember that (1) the receiver must be in tune with the transmitter; (2) the transmitter must be in tune with the receiver; (3) the transmission line must be in tune with the transmitter and antenna; and (4) the antenna must be in tune with the transmission line.

When all these conditions are met and ideally peaked for a single frequency, as is normally the case in two-way communication, results of amazing magnitude are obtained with respect to range, strength, and quality of signals. No tunable radio receiver for general broadcast reception covering a wide range of frequency can even begin to approach these results on a comparable frequency, even when working with a much more powerful broadcast transmitter. Efficiency, antenna design, and placement exceed by hundreds of times mere increased transmitter power. These should never be neglected. There are many radio systems in existence that could meet their requirements with much simpler lower-powered and less costly equipment, as to initial cost or subsequent maintenance, than they are actually using and get even better results if they heeded these considerations.

8 Vacuum Tubes

Vacuum tubes normally are the principal item of replacement and cost, once a system is installed and paid for. The only other comparable item should be the power from the electric light company to energize the equipment in the case of fixed stations. In mobile stations, the power charge does not exist, since power comes from the storage battery already in the car.

Tubes decline in efficiency and eventually become increasingly inoperative long before their filaments burn out, except in rare cases where the filament is defective or the tubes have been operated at excessive heater voltage. As a tube ages in service, it becomes weaker rather than inoperative, so that the equipment becomes less efficient. This is manifested in weaker signal strength and somewhat reduced satisfactory range of communication. Tube life is indefinite. Actual experience with hundreds of fixed and mobile units in various services shows that useful life periods can be expected up to 10,000 operating hours over a period of several years.

In the case of the Cape Cod system, the headquarters transmitter was equipped with a filament voltage-dropping resistor, so that instead of a 6-volt operating voltage during actual transmission the equipment stands by at 5½ volts whenever the microphone switch is released and

no transmission takes place. This greatly increased the tube life. The costlier high-powered tubes in the final amplifier stage (HK54) gave a useful life, exceeding 35,000 operating hours over a period of more than five years. Other tubes in preceding stages equipped with the same feature also had extended operating life. Whether this should be provided for all tubes is a matter of choice. Most of the tubes are inexpensive and can be replaced much sooner without burdensome cost, since they cost less than a dollar each, except for the final amplifier and, in the case of AM, for the modulator tubes. In mobile stations, no tube costs as much as five dollars even in the most powerful units.

Generally speaking, all tubes in two-way equipment, either fixed or mobile, should average for a system about 5000 hours each of actual service, that is, while lighted, regardless of whether they are transmitting, receiving, or standing by. Just how long a tube lasts depends on the station's replacement policy: whether to replace a tube as soon as it registers some reduction in emission as compared to a new tube; or whether to use it until it is definitely and very pronouncedly resulting in reduced signal strength and operating range to an unsatisfactory degree as determined by the requirements of the system.

The average system should ordinarily possess more volume and range than it needs when all tubes are ideally new. This means that satisfactory communication is still possible even when the tube efficiency has decreased with time and use. While it is not desirable to let the tubes remain in use to the danger point where they burn out or short out, it is not necessary to incur replacement expense when efficiency has decreased a negligible amount, as indicated on a sensitive tube tester but not actually manifested in normal communication. Even then, if cost is important, a subnormal tube can be tolerated for several hundred additional hours, in a later point in the circuit, provided it is not an early stage. A poor tube in an early stage of the receiver, followed by several stages of amplification, should be replaced immediately or exchanged with a stage further along in the circuit. Otherwise, a small reduction in efficiency in an early stage will amplify the deficiency of the poor tube to an enormous amount further along in the circuit.

Tube Tester. A tube tester shows the efficiency of a tube, using the correct or equivalent voltage-load conditions that the tube is designed for. However, the tube tester fails to duplicate the frequency at which the tube will be employed. This is unfortunate, and it is hoped that eventually a tube tester will be available that will duplicate this condition, to permit more ideal testing of tubes used in critical parts of a circuit. On frequencies exceeding 30 megacycles, it is actually possible for one or even several identical tubes to test perfectly in a tube tester and yet break down

in actual communication service because of the high frequency of operation. Yet the same tube might be satisfactory for low-frequency operation. Some of the cut-rate tubes on the market may be high-frequency reject tubes that, while satisfactory for medium-frequency or even high-frequency operations, are definitely undependable for very high frequencies in those parts of the circuit where such high frequencies are handled.

Therefore, it is advisable not to place complete reliance on the tube tester when the higher-frequency portion of the radio spectrum is utilized. Instead, tubes used as oscillators, frequency multipliers, and radio- and intermediate-frequency amplifiers should be tested by comparison or substitution with other tubes of known efficiency as well as by testing on the tube tester. The tube tester can show whether or not the filament is burned out, if emission is satisfactory on low frequencies, and whether or not any of the parts are touching each other and shorting. If emission is not good on low frequencies, it is not good on high frequencies.

Substitution will show whether the tube is able to function at the desired frequencies. It will also show whether the elements inside have the correct spacing between them, so that their interelectrode capacitances and transit times are satisfactory. No tube tester is able to do this. The tube tester will show that the elements are not touching each other; it will not show how far apart they are. Substitution will not do so either, but it will show whether the distances are sufficiently correct to obtain satisfactory operations.

Voltage Readings. When measuring socket-prong voltages to see whether they correspond with a set of socket voltages, such as is frequently included in manufacturers' instruction manuals, there may appear to be great discrepancies between the voltages given in the manual and those actually obtained by the technician in the field. The equipment may be functioning very satisfactorily despite an apparent discrepancy. This would be normal in many cases, because what the voltage will be depends on the circuit involved and whether an adjustable part, such as a resistor, is in series with the circuit. Most variable adjustments are actually small rheostats, varying voltages somewhere in the circuits. What the voltage or the resistance of such a circuit will be depends on their settings in many cases. An exception may be the filament voltages where there are no variable provisions to control the potential.

When a discrepancy is noted, it is suggested that before deciding the equipment is faulty an effort first be made to vary the controls to see whether the instruction manual voltages can be developed in that manner.

CHAPTER NINETEEN

LICENSES AND REGULATIONS

1 Federal Communications Commission

The Federal Communications Commission regulates interstate and foreign communication by wire and radio in the United States and its possessions as follows:

1. Licenses radio stations.
2. Issues call letters.
3. Allocates frequencies.
4. Decides band widths.
5. Licenses radio operating personnel.
6. Decides form and manner of modulation.
7. Establishes toll rates for stations in public service.
8. Conducts monitoring and checking services.

For radio communication, the FCC established the following principal classifications for emissions:

A1—Telegraphy using pure continuous wave. This is comparable to keying a radio carrier wave.

A2—Modulated telegraphy. A carrier wave modulated at one or more audible frequencies; the audible frequency or frequencies, or their combination with the carrier wave, being keyed according to a telegraph code. This is comparable in sound with using a radiotelephone transmitter where a keyed tone is fed into the microphone, except that no microphone is actually necessary and direct connection can be made to accomplish the same purpose.

A3—Telephony. Waves resulting from the modulation of a carrier wave by frequencies corresponding to voice, music, or other sounds. Two-way radio as discussed in this book is A3.

A4—Facsimile. Waves resulting from the modulation of a carrier wave by frequencies produced at the time of the scanning of a fixed image with a view to its reproduction in a permanent form.

A5—Television. Waves resulting from the modulation of a carrier wave by frequencies produced at the time of the scanning of fixed or moving objects.

On behalf of the Civil Aeronautics Administration or in conjunction with that body, the FCC regulates the location, height, and markings of

radio towers or masts that might otherwise be a menace to aviation. These cannot be changed without its authority.

The Commission sets forth the frequency tolerance which will be permitted, that is, how much a station may drift in frequency without violating the rules. For example, on 30 to 40 megacycles, this may be .01 per cent, since crystal control is feasible there. On microwaves, it may be different, because spectrum is more plentiful and frequency control techniques are not so well developed there at present. The frequency tolerance is more and more rigid as the frequency is lowered, due to the reduced frequency spectrum. It is especially severe in the broadcasting bands where disruption of reception of closely congested stations would otherwise result.

The FCC regulates the maximum amount of power that each station may use, particularly on channels shared by many stations, so that one station able to afford or provide more power will not have an excessive advantage over other stations. It also ferrets out hidden or undesirable motives of applicants or holders of station or operator licenses, and bars such individuals where this serves the public interest.

The Commission sets forth rules about the keeping of a log and the length of time for retaining such records, so that they may be referred to on any question that might arise. It inspects radio stations to which it has granted licenses. The more important ones are inspected at least once each license period. Other stations are inspected at random periods or by selection, consistent with the magnitude of the task.

The Commission regulates communication and can penalize individuals by fine, imprisonment, or revocation or suspension of either station or operating license or both. It enforces regulations prohibiting the transmission of superfluous or profane transmissions. It prohibits messages from being divulged to other than the persons for whom the transmissions are intended or who are authorized to receive them. It ascertains that stations are built and utilized in accordance with their license authorization.

Any person requiring radio facilities or permission to operate them may apply to the FCC. Stations and operators that function in accordance with their authorizations are protected, and the Commission corrects any inequities that develop in the allocation or utilization of radio facilities.

The Federal Communications Commission is the logical development of many years of experience following an initial era of confusion due to lack of regulation and agreement in the United States and abroad. Since the field it regulates is undergoing continual expansion and developing innumerable offshoots, the Commission, its predecessors, and future successors have been subject to change or revision every few years.

Aviation radio brings it in contact with the Civil Aeronautics Administration. Railroad radio brings it in contact with the Interstate Commerce Commission. Electronics involve many groups in the field of entertainment, medicine, industry, transportation, physics, chemistry, and optics.

The FCC regulates possible interference with radio reception; it does not regulate radio reception.

For purposes of two-way communication, except for limited induction radio applications, every radio station transmitter must be licensed, and at least one of the personnel must have a radio license. Under some conditions, all persons operating the equipment must have at least a permit, while the person making adjustments that could cause off-frequency operation requires a license.

It is to be expected that FCC requirements will be simple where spare frequency space exists and more complicated where this is not the case. This means that lower frequencies having ionospheric reflections will have rigid supervision, while such frequencies as ultra high or super high, where the spectrum is plentiful and sky-wave reflections are uncommon or unknown, will have lenient supervision.

Regulation by the Radio Profession. The Federal Communications Commission is interested in the over-all picture and has no greater interest in one group or utilization than in another. However, it does recognize and welcomes suggestions from organizations interested in specific fields, which are formed or reformed from time to time in keeping with their needs. Some of the present organizations are:

1. Radio Technical Planning Board, organized by the Institute of Radio Engineers and the Radio Manufacturers Association. It is made up of various panels, each having several members who represent a cross section of the entire radio field. At present some 500 experts serve without remuneration in these various panels. Their work is invaluable in the reconversion of the radio-frequency spectrum from wartime to peacetime utilization.
2. Institute of Radio Engineers, representing most of the radio engineering talent and many radiophysicists of the nation.
3. Radio Manufacturers Association, representing most of the radio manufacturing industry both for complete equipment and component parts.
4. Associated Police Communication Officers, representing many local and state police departments.
5. American Radio Relay League, representing most of the licensed radio amateurs in the United States.
6. National Association of Broadcasters, representing the broadcasting field.
7. Various other groups, such as the Association of American Railroads, for the railroad field; the FM Broadcasters, Inc., representing broadcasting stations utilizing FM; regional police, fire, and forestry radio groups; the International Association of Police Chiefs.
8. IRAC, the Interdepartment Radio Allocation Committee, representing all civilian and military departments of government.

2 Emergency Services

Radio communication for emergency purposes is defined as emergency service. This includes all police, fire, forestry, sheriff, public utilities, and other stations that might have occasion to operate primarily in emergencies.

A station used by a municipal or county police department for emergency radiotelephone service with mobile police units is called a municipal police station; when used by a state police department for the same purpose, it is called a state police station.

A station used for communication between municipal fire departments and fireboats is called a marine fire station.

A station used in lieu of normal means of communication is called a special emergency station. This is the designation for most uses of radio when supplementing wire facilities in any field of application, such as during periods of wire prostration, and it is also used for remote locations where other means of communication are not available.

A station used for communications in the forestry services is called a forestry station.

Eligibility for Licenses. Police stations are authorized only to instrumentalities of government. Fire stations are issued only to municipalities.

Forestry stations are issued to municipal, state, or private organizations that are legally responsible for the protection of forest areas.

Special emergency stations are authorized only to (1) organizations established for relief purposes in emergencies, having a disaster communication plan; (2) persons having establishments in remote locations which cannot be reached by other means of communication; and (3) public utilities.

Licenses for stations are applied for individually for the fixed stations. Blanket applications may be made for one license to cover all or several units of identical mobile, portable-mobile, or low-powered portable transmitters to be used in a single co-ordinated communication system.

3 Experimental Services

A service conducted by a station engaged in research and experimentation for the further development of the radio art is called an experimental service. Such services have been invaluable in opening up the field of two-way radiotelephone communication. At one time or another every radio application was under an experimental license. From 1932 to 1938, two-way police radio on the 30 to 40 megacycle band operated with experimental license. For example, on Cape Cod, 39,900 kilocycles AM, a typical call was W1XFB. Broken down this means:

W—United States.
1—First radio call district (namely New England).
X—Experimental.
FB—Identification of a particular station.

After 1938, when the service was found to be no longer experimental, but instead feasible and indispensable, it obtained a regular emergency license with a standard four-letter call WRAQ. When FM became available, the South Portland, Maine, system operated the first year experimentally with similar call letters. After it was proved feasible, it received a standard four-letter call.

Experimental stations are of three general classes which provide considerable latitude for new and expanding utilizations in the field of two-way radio.

Class 1. This class of station is authorized to persons engaged in fundamental, general, or specific radio research and experimentation directed toward the advancement of the radio art but not connected with any proposed or established radio service. The license is issued after a satisfactory showing in regard to the following:

1. That the applicant is primarily engaged in (a) fundamental research or unsolved technical problems and unproved scientific theories; (b) developing, testing, or calibrating of radio equipment; or (c) general research, experimentation, and development of the radio art.
2. That the applicant is a corporation, institution, manufacturer, research and design laboratory, or an association or individual particularly qualified to carry forward the proposed program of research.

Such stations must submit an experimental report at license renewal time to the Federal Communications Commission, which must include comprehensive information on the following, in the order designated:

1. Final objective of the experimental program.
2. Report on the research and experiments conducted.
3. Detailed analysis of the results obtained.
4. Copies of any published reports on the experimental work.
5. A list of the patent numbers of any patents during the license period as a result of the experimental work accomplished in this or previous periods.
6. Any major changes made in the equipment.
7. Any other pertinent information.
8. The need for the continuation of the experimental program of research and the necessity for the renewal of the station license.
9. Total number of hours of operation on each frequency.

Class 2. This class of experimental station is authorized to persons engaged in research and experimentation in radio directed toward the development of a new or proposed radio service, or some phase of an

established radio service. A satisfactory showing is required with respect to the following:

1. That the applicant is primarily interested in research and experimentation in radio directed toward the development of a new and proposed radio service or some phase of an established radio service.
2. That the requirements set out for experimental operation under the service involved will be met.

Such stations must also submit an experimental report at the annual license renewal period containing the same information applicable to Class 1, except that item 7 must contain the following pertinent information:

(a) Frequencies believed to be more suitable and reasons therefor.
(b) Probable public support and methods of its determination.
(c) Practicability of service conditions.
(d) Interference encountered.
(e) Pertinent information relative to merits of proposed service.
(f) Propagation characteristics of frequencies used, particularly with respect to service objective.
(g) Type of signals or communications employed in the experimental work.

Class 1 and Class 2 experimental stations are also required to make a satisfactory showing with regard to the following:

1. That the applicant has an organized plan of research leading to a specific objective.
2. That the applicant has a program of research and development that has reached a stage in the laboratory where actual transmission by radio is essential to the further progress of the experimental program.
3. That the program of research has reasonable promise of substantial contribution to the expansion or extension of the radio art or is along lines not already investigated.
4. That the program of research and experimentation will be conducted by qualified personnel.
5. That the applicant is legally and financially qualified and possesses adequate technical facilities to carry forward the program and has made adequate financial appropriations toward this end.
6. That experimental stations shall only be operated in such a manner and at such times as to preclude interference with established stations or services.
7. That the requirements for obtaining a license for the particular class of experimental station applied for will be met.
8. That the public interest, convenience, and necessity will be served through the operation of the proposed station.

Class 3. This type of authorization is granted to a citizen interested in the radio technique solely with a desire to conduct an experimental program on his own behalf, requiring the use of radio for a limited time. A satisfactory showing is required in regard to the following:

1. That the applicant has a definite program requiring the use of radio and facilities necessary to carry forward the program as proposed.
2. That the proposed experiments will be conducted on the frequencies assigned for this class of station.
3. That the experiments can be completed in a reasonably short time and that applications for renewal will not normally be necessary.
4. That the applicant is a citizen interested in radio technique with a desire to conduct an experimental program on his own behalf requiring the use of radio for a limited time.

Such licenses are granted on a temporary basis only with the express understanding that the authority to use the frequency or frequencies may be canceled without advance notice or hearing. To renew such authorization, an application must be filed giving:

1. A complete technical description of the objective and results of the experimental program conducted.
2. A satisfactory showing that the objective of the experimental program has not been attained and that the results indicate the possibility of completing the program within a reasonably short time.

Class 3 stations are not permitted to carry on two-way radio communication. Only such test messages as are necessary to conduct the experimental program may be transmitted by this class of station. However, two-way communication can be carried on with a Class 2 experimental license.

4 Marine Radiotelephone Services

There are two types of marine radiotelephone service. One is concerned with vessels that are required by law to maintain radio communication, such as seagoing vessels of a specific tonnage or passenger capacity. This type is not discussed in this book because an entirely different frequency spectrum and usage is involved. Such stations require rigid regulation by the U.S. Steamboat Inspection Service and other regulatory bodies. Much of their operation is conducted by radiotelegraphy.

The type described in this book is for craft not necessarily required by law to carry radio. But regardless of the craft, the following radio communications must be given precedence:

1. Distress calls, distress messages, and distress traffic have absolute priority.
2. Communications preceded by an urgent signal rank next in priority.
3. Communications preceded by a safety signal.
4. Communications relating to radio direction-finder bearings. Stations are expected or required to communicate with each other without regard to the country to which these stations belong.

5 Aviation Services

The following terminology and rules apply to aircraft for purposes of licensing.

The term, Aviation Services, means radio communication or special service carried on by aircraft stations, airport control stations, aeronautical stations, aeronautical fixed stations, instrument landing stations, and flying school stations.

A radio station on board any aircraft (either heavier or lighter than air) is called an aircraft station.

An aircraft regularly flying a fixed route is called a scheduled aircraft.

An aircraft that does not fly a fixed route regularly is called a non-scheduled aircraft.

A radio communication service to provide public communications to, from, and between aircraft in flight by means of paid or toll messages is called a public aviation service.

A station used primarily for radio communication with aircraft stations is called an aeronautical station. Such a station may also carry on a limited fixed service with other aeronautical stations in connection with the handling of communications relating to the safety of life and property in the air.

A station used in the fixed service for the handling of point-to-point communications relating solely to aviation needs is called an aeronautical fixed station.

A series of co-ordinated stations in the aviation service, operating on frequencies allocated to aviation services in accordance with a plan approved by the FCC, is called a chain of stations.

A station for communications limited to aviation needs between an airport control tower and aircraft stations in the immediate vicinity of the airport is called an airport control station. By immediate vicinity is meant within 30 miles ground distance or 10 minutes' flight of the airport.

A station used for communications pertaining to instruction of students or pilots while in flight is called a flying school station.

A special service station to facilitate the landing of aircraft is called an instrument landing station. It may include one or more of the following: glide path transmitter, localizer transmitter, combination glide path and localizer transmitter, approach marker transmitters.

A station marking a definite location on the ground as an aid to air navigation is called a radio marker station. It may be any one of several types, such as fan marker, inner marker, outer marker, or Z marker. If a marker station is installed as part of an instrument landing system, it is not licensed separately.

Station licenses must be conspicuously posted at the place where the control operator is located, except that in aircraft stations the license may be posted or kept at any convenient accessible location in the aircraft.

Operator licenses (original) must be conspicuously posted at the place where the operator is on duty, or in the case of mobile units either the license or verification card must be kept in the operator's personal possession.

Equipment and service on the air may be conducted only if necessary precautions are taken to avoid interference with any station. If in range of an airport control station or CAA station, it may only be done after permission is secured from such stations if the frequencies are the same as those used at such stations; for example, 3105 and 6210 kilocycles.

All stations in the aviation service except aircraft stations must keep an adequate log showing (1) hours of operation, (2) frequencies used, (3) stations with which communication was held, and (4) signature of operator on duty.

These logs, except for public aviation service stations, may be destroyed after a period of three months except in those circumstances where retention of the logs for a longer period is specifically provided for in other rules. Longer retention may be advisable if the log records an accident, infraction of rules, or data which might be useful in connection with a hearing or investigation by the Federal Communications Commission or the Civil Aeronautics Administration.

For purposes of identification, the aircraft name, company number, trip number, official registry number, or other identification approved by the FCC may be used in lieu of the call letters, provided that adequate records are maintained to permit ready identification of individual aircraft. Also, the name of the city or airport in which other classes of stations are located may be used in lieu of the call letters of the station when using telephony. In the case of stations using telegraphic emissions, the call letters designated in the license must be used at the end of each sequence of communication to one or more stations.

In aviation communications, messages that pertain to the safety of life and property have priority, and no transmissions may be made that delay or interfere with such communications.

6 Amateur Radio

Amateurs form the largest single group of individuals interested in radio, and they are the most prolific source of radio development. Prewar their number was about 50,000 in the United States, representing several times more than in the rest of the world.

In time of war when a nation spends unlimited funds and musters all available talent, technical developments are made at terrific expense. In time of peace when government financial support does not exist, the amateurs are a most important source of development.

Nothing makes radio more popular and enjoyable than the privilege of engaging in amateur radio with the approval and understanding of a friendly government. No amount of capital and available scientific personnel can compare with the output of ideas and findings of the radio amateur. These amateurs make innumerable major contributions in the fields of communications and electronics because of their great number, wide geographical distribution, genuine interest, ingenuity, resourcefulness, and tendency to do things in their own way. Since they often lack advanced conventional knowledge and methods or facilities, they proceed without recognizing the theoretical lines of approach and computations, and they are less subject to discouragements resulting from ignoring or overlooking relevant factors than are the professional physicists and engineers.

The amateurs include professionals as well as laymen or novices. A professional can be classed as an amateur if he also engages in his field as a hobby or in spare-time participation along lines of approach different from his regular compensatory employment. An amateur can do things any way he pleases, so long as he does not violate federal regulations pertaining to interference on the air or superfluous or illegal communication.

The amateur, frequently using a raw development and odd or castoff radio parts, by great perseverance, love for his hobby, and skill of hands and mind, develops many interesting ideas, which then may revert to the professional for more complex development. For example, a physicist in a laboratory may develop a short-wave technique which seems to have limitations. It is reported in a technical journal in very technical language. An amateur journal reports it further in less technical language, and amateurs take it up. They get interesting results or discover useful offshoots which become known. Then engineers and manufacturers become interested, and, backed by funds and support, the technique begins to have wide application and usefulness. Very high frequencies is an example of such a line of development. Thousands of amateurs, aided by their number, varied locations, and interested participation, discovered facts about sky-wave behavior, skip distances, and frequency behavior, and correlated their experiences. No single firm or research group could have provided such an elaborate survey, handled so enthusiastically and capably.

The amateur is needed in the postwar period to continue such efforts

in connection with new developments in microwaves, television, FM, facsimile, and many other radio offshoots. The Federal Communications Commission for the Government and the American Radio Relay League for the organized amateurs protect amateur activity in the United States. They fight off all efforts at international conferences to restrict or abolish the amateur, as many countries where rigid control of all activity is common have tried to do. So long as amateur radio is encouraged in the United States, new uses for radio and electronics will be developed.

The following terminology and requirements for amateur radio are set forth by the FCC.

A radio service carried on by amateur stations is termed an amateur service.

A station used by a duly authorized person interested in the radio technique solely with a personal aim and without pecuniary interest is called an amateur station.

A person holding a valid license issued by the Federal Communications Commission authorizing him to operate a licensed amateur station is called an amateur operator. There is no limitation as to age or sex, so long as the person is a citizen of the United States.

Radio communication between amateur stations solely with a personal aim and without pecuniary interest is called amateur radio communication.

An amateur station that is portable in face, that is so constructed that it may conveniently be moved from place to place for communication, and is in fact so moved from time to time but is not operated while in motion, is called an amateur portable station.

An amateur station that is portable in fact, that is so constructed that it may conveniently be transferred to or from a mobile unit or from one such unit to another, and is in fact so transferred from time to time and is ordinarily used while such mobile unit is in motion, is called an amateur portable-mobile station.

Licenses for amateur stations are issued only to licensed amateur operators.

Every amateur radio station uses assigned call letters. These are broken up into nine call districts in the United States. The first letter of the call indicates the nationality of the amateur station. The second character is a numeral indicating the call area of the United States and its possessions. The subsequent letters are the assigned call letters for that area and nation.

In time of emergency, amateur stations may communicate with regular stations if conditions warrant.

An amateur station must not be used to transmit or receive messages for hire nor for communication for material compensation, direct or

indirect, paid or promised. It also cannot be used for broadcasting entertainment in any form or for the transmission of music.

7 Licensing of Radio Stations

Every station that utilizes a transmitter must be specifically licensed by the FCC in the United States or equivalent agency in other nations. Stations that only have receiving equipment do not require licensing in the United States. In some countries a tax may be required rather than a license for revenue purposes primarily. Taxes thus far have not been imposed in the United States on operating stations. Thus far, all permits and licenses issued by the FCC as well as any services that the Commission performs are free.

The station license should be conspicuously posted in the room where the transmitter is located. In the case of mobile stations, it shall be at the headquarters fixed station or, if that does not exist, then available for inspection in the vehicle.

In congested areas, some organizations advise the applicant as well as the FCC on the feasibility of the application's frequency, to the end that a frequency is chosen which will cause no, or minimum, interference with other services. These setups change from time to time. Typical ones are: Eastern States Police Radio League, Police Headquarters, Boston, Massachusetts, serving the New England area; and Associated Police Communication Officers, Missouri State Police, Jefferson City, Missouri.

Sufficient copies should be submitted according to the instructions from the FCC. When applying for a license for the first time, visit or write the FCC either at Washington or any of its district offices. Usually it will be simpler to write to the Washington office, which will supply forms and literature on the procedure. Requirements change from time to time as radio expands in utilization and development.

Applying for a station license for an important service may justify mention of the following:

1. Vital public need which cannot otherwise be met.
2. Vital military need.
3. Size of area.
4. Population of area.
5. Size of organization.
6. Expansion of activities.
7. Present means of communication if any.
8. Lack of a suitable station near by.
9. Reasons why no other means can be used to effect the desired service.
10. Traffic or police problems created by present or local conditions or from close proximity of certain activities.

All these should if possible be substantiated by letters from dependable sources.

In general the following rules apply to stations:

The applicant and the owner must be a citizen of the United States. No foreign person, firm, or government may own or have a voice in the control of the station.

The station license must be posted where the transmitter is located except where it is obviously impossible to do so. It should then be located where the equipment is controlled or kept otherwise convenient for inspection by a representative of the Federal Communications Commission.

The equipment must operate on the assigned frequency or within the allowed frequency tolerance. Facilities should be provided to make certain that this state of affairs exists.

A log must be kept of the communications handled by a transmitter. Where both fixed and mobile stations are involved in a system, only the fixed station needs to keep the log.

A station is ordinarily licensed for one year; in the case of amateurs, three years. This may be changed as the FCC may decide. The rapid advance of radio has not made it feasible to grant licenses for longer periods. Usually licenses expire at a certain time in the year for a particular class of stations. This permits the FCC to distribute its administrative load.

When a station receives a construction permit, it will contain the call letters. Ordinarily a construction permit is tantamount to a license. The application for license that follows the construction permit is largely a confirmation that the station was built in accordance with the terms of the permit. Otherwise, there would be no way of determining whether the construction permit was actually used and the channel occupied. If the license application is not made immediately following the period mentioned in the construction permit, it is assumed that no action was taken by the prospective licensee. The permit then becomes void, and the channel may be reassigned by the FCC to another applicant.

All stations shall be available for inspection by the FCC during operation at any reasonable hour.

Concealment, falsification, or misrepresentation of the ownership, control, location, affiliations, motives, or channel utilization of stations make the individuals responsible liable to imprisonment, fine, suspension, or complete revocation of either or both of the station and operating licenses. For example, no one must apply for a broadcasting frequency in a spectrum where the channels are so scarce that they have great monetary value, and then sell or make it available to someone who is not eligible or who already has a channel. Monopoly of radio broadcasting

channels by secret combines is definitely discouraged; if discovered, the licensees will lose their privileges and be subject to drastic penalties if the offense warrants doing so.

Stations that do not operate on clear channels and share a common frequency with other stations in the same service do not require a construction permit in advance of license. The same form acts as both construction permit and station license. This includes amateurs, vessels, and planes. Stations that have a clear channel at least locally, such as police, fire, forestry, or railroads, require a construction permit before they can obtain a license. This is necessary to permit the licensing authority to study the case from the standpoint of the effects the new radio facilities may produce in the way of interference, improper operation, or channel congestion, affecting prior users as well as the prospective licensee.

Stations must not exceed the power indicated nor be used for transmissions and forms of modulation other than applied for and authorized.

In the case of fixed stations, the towers must be lighted and painted in accordance with requirements and recommendations of the Civil Aeronautics Administration, particularly where a height of 100 feet is exceeded. As they loom higher than surrounding structures and terrain, the towers must be so located and marked that they will be a minimum menace to aviation and instead will serve as useful landmarks. The painting scheme is designed to offer maximum contrast by day, and the lighting scheme maximum contrast by night.

Equipment may be bought and sold without a license. However, no equipment can be used without a license. The license cannot be transferred or sold during the license period, except where the FCC sanctions this. If the permittee does not use the license or stops using facilities covered by the license, the privilege becomes invalid and void.

8 Licensing of Radio Operators

International radio convention and the Federal Communications Commission require that the person who operates a radio station for which a license is required must hold a radio operator license of the required class. Current license requirements may be obtained from the Federal Communications Commission.

A license or permit may be revoked for reasons such as:

1. Violating the Communications Act, or any act, treaty or convention binding on the United States. Penalties up to $10,000 and two years' imprisonment may be imposed.
2. Violating any regulation of the FCC. The penalty may be as much as $500 a day per offense in addition to suspension or revocation of station or operator licenses, or both.

3. Failure to carry out the lawful commands of a master or person in charge of a ship when serving in a radio capacity.
4. Damaging, or permitting to become damaged, radio apparatus or equipment.
5. Transmitting superfluous, false, or deceptive signals or calls.
6. Using indecent language.
7. Obtaining, attempting to obtain, or assisting another to obtain or attempt to obtain a license by fraudulent means.
8. Deliberate interference with other radio transmissions.
9. Revealing information to unauthorized persons or utilizing the same.

9 Conditions Requiring No License

No license is required, either for the equipment or for the person operating same, to receive radio transmissions, so long as the nature of the transmission is not disclosed or utilized directly or indirectly by unauthorized persons.

Neither is a license required where a licensed operator is at all times on duty and in control of a two-way radiotelephone system while it is in operation, so long as permission has been obtained from the Federal Communications Commission to operate in this manner.

No license is required for certain low-power radio-frequency devices, such as induction forms of communication that do not have an electromagnetic field exceeding 15 microvolts per meter at a distance in feet of 157,000 divided by the frequency in kilocycles from the apparatus, provided that they do not interfere with other radio licensees.

It is believed that the technical requirements for a license or permit will be liberalized or even omitted for mere operation of equipment for simple or personalized uses in the future on microwave frequencies. This may become increasingly true where the equipment has purely local coverage and the service gains in popularity with universal use. The retention of some degree of control with respect to heeding radio laws as regards superfluous communication, use of profanity over the air, handling or undertaking illegal or criminal communications, or violating and disclosing signals to unauthorized persons or utilizing the same is desirable for the common interest.

10 Postwar Frequency Allocations

On September 28, 1944, the Federal Communications Commission held public hearings in the matter of allocation of frequencies to the various classes of non-governmental services in the radio spectrum from 10 kilocycles to 30,000,000 kilocycles. This hearing became known as FCC Docket No. 6651.

The purpose of this hearing was to allocate a new frequency spectrum

which became feasible to utilize solely as the result of radio-electronic progress in World War II. Pre-war licensees were little interested in frequencies exceeding about 120,000 kilocycles because of the absence of suitable equipment and techniques. Now the spectrum was opening up to 30,000,000 kilocycles, or 250 times further. In addition, all this new spectrum was free of sky-wave or ionospheric skip behaviour so far as is currently known, thereby making it possible to reallocate completely this vast frequency spectrum over and over every 25 to 50 miles on the earth's surface in every direction. For the first time it began to be possible for every individual in the world to have two-way radio communication under reasonably satisfactory conditions, even in the most congested communities, provided beamed transmissions were utilized.

On January 15, 1945, the FCC released a report entitled "Proposed Allocation from 25,000 Kilocycles to 30,000,000 Kilocycles." On May 25, 1945, this proposed report became a final report modified slightly from the previous one in order to meet objections advanced by FM broadcasting and television interests involving a small portion of the overall spectrum. This was followed by a report covering the sky-wave frequencies subject to ionospheric reflections and long-range skip from 10 to 25,000 kilocycles. The latter report involves such a small amount of the total radio spectrum that it is both inadequate and unfeasible for extensive two-way radio communication of the type discussed in this book. This is due to the inadequacy of the overall frequency spectrum it represents, inability to share the same channels without interference except where great separations in distance exist between stations, and the international aspects that arise where reflections from the ionosphere cause ranges extending beyond a nation's boundaries.

The September, 1944, FCC hearings indicated that in most cases, the request for frequencies by the various non-governmental radio services far exceeded the supply, despite the large amount of new spectrum under consideration. In some cases the evidence showed little or no correlation between the number of channels requested and the number and locations of the united proposed to be installed. To meet this situation, the Federal Communications Commission guided itself by six general principles as follows:

1. Each request was examined to determine whether the service in question really required the use of radio or whether wire lines were a practicable substitute. This took into account economic and social factors and considerations of national policy, particularly with respect to great disparity in communication costs. This was particularly true on all frequencies below about 200 megacycles.

2. To give prior consideration to radio services necessary for safety

of life and property over those which were in the nature of a convenience, a luxury, or a novelty.

3. The total number of people who would probably receive benefits from a particular service. Other factors being equal, preference was given where large groups of the population, instead of relatively small groups, would benefit.

4. Where new services were involved, a determination whether such newer services met a substantial public need and what the likelihood was, if frequencies were granted, that the service could be established on a practical working basis.

5. A determination of the proper place in the spectrum for the service in question so that it could render its best service.

6. Where competing requests for certain frequencies arise, consideration is given to the number of transmitters and receivers already in use, the investment of the industry and the public in equipment, and the cost and feasibility of converting the equipment for operation on different frequencies, as well as the time required for an orderly change to the new frequencies.

There has been a tendency for landline communication companies and very large radio firms to seek huge blocks of channels on the super high frequency band between 3,000 and 30,000 megacycles for their exclusive use, principally for the purpose of charging tolls on radio services they propose to perform. This has already been viewed with alarm by others not so fortunate. To them it means they must pay toll or tribute, direct or indirect, for services that they could otherwise provide at least in part. While the word "monopoly" might be implied in this situation, it need not be so if users may also have spectrum for independent use and the industry as a whole may continue to manufacture and sell the equipment to the users to function with such networks.

The granting of reasonable channel space to wire communication companies as represented by the American Telephone and Telegraph Company will make it possible for two-way radio users to enjoy the advantages of communicating with any point that a home or office telephone subscriber enjoys. This is definitely advantageous and in the public interest. The danger to the radio industry and to the public will come if at any time this results in a situation where the mobile or portable equipment users are required only to use, buy, or lease equipment manufactured by a subsidiary of the operating company or are deprived of the privilege of using the toll facilities. The solution appears to be for the Telephone Company to confine itself principally to operating toll-fixed facilities, and for the equipment required by the users to be manufactured by any or all radio firms. The public should be at liberty to buy, build, or

lease satisfactory equipment wherever it may please to do so. This equipment could be multi-channel equipment to permit free personalized direct communication where possible, as well as tie-in with the toll radio/landline facilities of the American Telegraph and Telephone System now being established on an increasing scale. A satisfactory basis for doing this can be found in the pre-war marine or ship-and-shore activities of the same company described in the marine chapter of this book.

The frequencies finally approved by the Federal Communications Commission on May 25, 1945, are as follows:

ALLOCATION BY FREQUENCY

Megacycles	Utilization	Amount of Kilocycles
25 015 to 27 185	Gov't and non-gov't fixed & mobile	2,170
27 185 to 27 455	Scientific, industrial & medical	270
27 455 to 28 000	Gov't & non-gov't fixed & mobile	555
28 000 to 29 700	Amateur	1,700
29 700 to 30 000	Gov't & non-gov't fixed & mobile	300
30 000 to 30 500	Government	500
30 500 to 32 000	Non-gov't fixed & mobile	1,500
32 000 to 33 000	Government	1,000
33 000 to 34 000	Non-gov't fixed & mobile	1,000
34 000 to 35 000	Government	1,000
35 000 to 36 000	Non-gov't fixed & mobile	1,000
36 000 to 37 000	Government	1,000
37 000 to 38 000	Non-gov't fixed & mobile	1,000
38 000 to 39 000	Government	1,000
39 000 to 40 000	Non-gov't fixed and mobile	1,000
40 000 to 40 960	Government	960
40 960 to 41 000	Scientific, industrial & medical	40
41 000 to 42 000	Government	1,000
42 000 to 44 000	Non-gov't fixed & mobile	2,000
44 000 to 108.000	Subject to adjustment, but provides 2 megacycles to facsimile, 4 megacycles to amateurs, 4 megacycles for non-government fixed and mobile, 4 megacycles for educational FM broadcasting, 6 megacycles for television broadcasting, 30 megacycles for television fixed and mobile, 14 megacycles for commercial FM broadcasting	64,000
108 000 to 118 000	Government	10,000
118 000 to 122 000	Airport control	4,000
122 000 to 132 000	Aeronautical mobile (primarily non-gov't)	10,000
132 000 to 144 000	Government	12,000
144 000 to 148 000	Amateur	4,000
148 000 to 152 000	Government	4,000
152 000 to 162 000	Non-gov't fixed and mobile	10,000
162 000 to 174 000	Government	12,000
174 000 to 186 000	Television and government	12,000
186 000 to 216 000	Television, fixed & mobile, with possibility of permitting non-government	30,000

Megacycles	Utilization	Amount of Kilocycles
	fixed and mobile services if necessary and it is feasible to share, on non-interfering basis	
216 000 to 220 000	Government	4,000
220 000 to 225 000	Amateur	5,000
225.000 to 328 600	Government (military) with adequate channels reserved for civil aviation	113,600
328.600 to 335 400	Air navigation aids (glide path)	6,800
335.400 to 400 000	Government (military) with adequate channels reserved for civil aviation	64,600
400 000 to 420 000	Government (including radio-sonde)	20,000
420 000 to 450 000	Amateur and air navigation, later to become entirely amateur	50,000
450 000 to 460 000	Non-gov't fixed and mobile	10,000
460 000 to 470 000	CITIZENS RADIO	10,000
470 000 to 480 000	Facsimile broadcasting	10,000
480 000 to 920 000	Television	440,000
920 000 to 940 000	Experimental broadcast services	20,000
940.000 to 960 000	Fixed and experimental broadcasting and low-power fixed point-to-point control circuits, etc.	20,000
960 000 to 1145.000	Navigation aids	185,000
1145 000 to 1245 000	Amateur	100,000
1245 000 to 1325 000	Television relay	80,000
1325 000 to 1375 000	Non-gov't fixed & mobile, including aero	50,000
1375 000 to 1600 000	Government	225,000
1600 000 to 1700 000	Air navigation aids	100,000
1700 000 to 1750 000	Meteorological	50,000
1750 000 to 2100 000	Non-gov't fixed and mobile	250,000
2100 000 to 2300 000	Government	200,000
2300 000 to 2450 000	Amateur	150,000
2450 000 to 2700 000	Non-gov't fixed and mobile	250,000
2700 000 to 2900 000	Meteorological and air navigation aids	200,000
2900 000 to 3700 000	Navigation aids	800,000
3700 000 to 3900 000	Air navigation aids	200,000
3900 000 to 4400 000	Non-gov't fixed and mobile	500,000
4400 000 to 5000 000	Government	600,000
5000 000 to 5250 000	Air navigation aids (instrument landing)	250,000
5250 000 to 5650 000	Amateur	400,000
5650 000 to 7050 000	Non-gov't fixed and mobile	1,400,000
7050 000 to 10000 000	Government	2,950,000
10000 000 to 10500 000	Amateur	500,000
10500 000 to 13000 000	Non-gov't fixed and mobile	2,500,000
13000 000 to 16000 000	Government	3,000,000
16000 000 to 18000 000	Non-gov't fixed and mobile	2,000,000
18000 000 to 21000 000	Government	3,000,000
21000 000 to 22000 000	Amateur	1,000,000
22000 000 to 26000 000	Government	4,000,000
26000 000 to 30000.000	Non-gov't fixed and mobile	4,000,000
above 30000.000	Experimental	unlimited.

ALLOCATIONS FOR SPECIFIC TWO-WAY RADIO SERVICES

Note: In most cases, these frequencies are available to more than one type of service on a non-interfering basis.

FIXED PUBLIC SERVICES (OTHER THAN IN ALASKA)

30 to 108 megacycles
152 to 162 megacycles
186 to 216 megacycles
940 to 960 megacycles
1,325 to 1,375 megacycles
1,750 to 2,100 megacycles
2,450 to 2,700 megacycles
3,900 to 4,400 megacycles
5,650 to 7,050 megacycles
10,500 to 13,000 megacycles
16,000 to 18,000 megacycles
26,000 to 30,000 megacycles

COASTAL AND SHIP SERVICES

30 to 40 megacycle band	30 channels.
42 to 44 megacycle band	25 channels.
44 to 108 megacycle band	(no definite number of channels)
152 to 162 megacycle band	32 channels.
186 to 216 megacycle band	(no definite number of channels)

AVIATION RADIO SERVICES

25 to 30 megacycle band	7 channels. . . Flight test, flying schools and feeder airlines.
118 to 122 megacycle band. .	20 channels. . . Airport control.
122 to 132 megacycle band. .	50 channels . . Aeronautical mobile.
225 to 328.6 megacycle band.	(no definite number of channels) . for government military and civil aviation.
335.4 to 400 megacycle band . . .	ditto
1325 to 1375 megacycle band.	Aeronautical mobile (experimental).

AMATEURS

28 to 29.7 megacycles
In region 44 to 108 megacycles, amateurs will receive 4 megacycles which will be either 44–48, 50–54 or 56–60 megacycles, depending on final determination of television and FM broadcasting requirements.

144 to 148 megacycles
220 to 225 megacycles
420 to 450 megacycles
1,145 to 1,245 megacycles
2,300 to 2,450 megacycles
5,250 to 5,650 megacycles
10,000 to 10,500 megacycles
21,000 to 22,000 megacycles
Also may share 30,000 megacycles and above with other services.

RELAY BROADCAST

in 25 to 30 megacycle band.	24 channels.
in 152 to 162 megacycle band.	12 channels.

920 to 940 megacycles
940 to 960 megacycles
1,325 to 1,375 megacycles
1,750 to 2,100 megacycles
2,450 to 2,700 megacycles
3,900 to 4,400 megacycles
5,650 to 7,050 megacycles
10,500 to 13,000 megacycles
16,000 to 18,000 megacycles
26,000 to 30,000 megacycles
above 30,000 megacycles.

POLICE RADIO

in 30 to 42 megacycle band	36 channels.
in 42 to 44 megacycle band	24 channels.
Either 74 to 78 megacycles or 104 to 108 megacycles (pending decision) providing	for 36 channels.
152 to 162 megacycles	36 channels.
940 to 960 megacycles	Experimental and miscellaneous.

Also may have frequencies in the television channel regions of 104 megacycles and 186 to 216 megacycles.

FIRE RADIO

in 104 to 108 megacycle band	12 channels of 50 kilocycles each.
in 152 to 162 megacycle band	12 channels of 60 kilocycles each.

FORESTRY AND CONSERVATION

in 30 to 40 megacycle band	29 channels.
104 to 108 or 74 to 78 megacycle band	14 channels of 50 kilocycles each (depends on final decision as to what part of band).
152 to 162 megacycles	12 channels of 60 kilocycles each.

940 to 960 and other higher experimental frequencies.

ELECTRIC, GAS, WATER AND STEAM UTILITIES

25 to 30 megacycle band	12 channels of 25 kilocycles each.
30 to 40 megacycle band	7 channels of 40 kilocycles each.
104–108 (or 74–78 alternative pending)	6 channels of 50 kilocycles each.
152 to 162 megacycle band	6 channels of 60 kilocycles each.

TRANSIT UTILITIES

30 to 40 megacycle band	11 channels of 40 kilocycles each.
104–108 (or 74–78 megacycle alternative pending)	6 channels of 50 kilocycles each.

May also share frequencies in the television bands on basis of need and non-interfering basis. Experimentation permitted in various bands beginning with 1345 megacycles allocated to non-governmental fixed and mobile services.

SPECIAL EMERGENCY

30 to 40 megacycle band ..	6 channels of 40 kilocycles each
104–108 megacycle band (or alternative 74–78 pending)	10 channels of 50 kilocycles each.

204–216 and 940–960 megacycles for automatic relay or repeaters.

PROVISIONAL RADIO SERVICE (intermittent service of necessary nature).

25 to 30 megacycle band	10 channels.
30 to 40 megacycles .	9 channels.
42 to 44 megacycles.	1 channel.

104–108 (alternative 74–78) megacycles	12 channels.
152 to 162 megacycle band	4 channels.
GEOPHYSICAL SERVICE	
25 to 30 megacycles	24 channels.
30 to 40 megacycles	4 channels.
42 to 44 megacycles	5 channels.
152 to 162 megacycles	16 channels.
MOTION PICTURE RADIO STATIONS	
25 to 30 megacycles	6 channels.
152 to 162 megacycles	12 channels.
RELAY PRESS	
25 to 30 megacycles	6 channels.
152 to 162 megacycles	4 channels.
RAILROADS	
152 to 162 megacycles	60 channels primarily for end-to-end and fixed point to train operation, etc.
1,325 to 1,375 megacycles	experimental and shared.
1,750 to 2,100 megacycles	" " "
2,450 to 2,700 megacycles	" " "
3,900 to 4,400 megacycles	" " "
5,650 to 7,050 megacycles	" " "
10,500 to 13,000 megacycles	" " "
16,000 to 18,000 megacycles	" " "
26,000 to 30,000 megacycles	" " "
above 30,000 megacycles	" " "

Also may ask for channels in 44–108 mc and 186–216 mc television regions.

BUS, TRUCK, TAXI, HIGHWAY RADIO TELEPHONE SERVICE COMMON CARRIER

30 to 40 megacycle band	20 channels.
42 to 44 megacycle band	20 channels.
152 to 162 megacycle band	24 channels.

These services are commencing on an experimental basis. Additional or other allocations will be made on the basis of experience and experimentation during the future. Once this service becomes widespread, all the channels of all the services below 162 megacycles would be inadequate. It would require entering the microwave region of experimental frequencies. This will be possible on various experimental and shared frequencies.

CITIZENS RADIOCOMMUNICATION SERVICE

460 to 470 megacycles used as a common band for any type of utilization. See detailed report on this service in the Personalized chapter.

RURAL RADIO TELEPHONE SERVICE.

Channels are available from among the 44 to 108 megacycle television regions, 118 to 216 megacycle region as well as from 24 channels in the 152 to 162 megacycle band. Also 1325–1375, 1750-2100, 2450–2700, 3900–4400, 5650–7050, 10500–13000, 16000–18000, 26000–30000 megacycle bands. All these bands are also assigned to other services. They may be made available on an appropriate geographical and mutually non-interfering basis. Being intended for outlying districts, this should make adequate channel space available without interfering with other services.

CHAPTER TWENTY

TYPICAL RADIO SYSTEMS

1 Village or Small Town

The township of Chatham, Massachusetts, has a year-round population of about 2000, increasing to 5000 or more during the months of July and August. It consists of the villages of Chatham, North Chatham, South Chatham, West Chatham and Chathamport. The police station is located in one room of the town hall on the main street of Chatham. The maximum air-line distance to the extreme ends of the township is about three miles air-line from the police station. The business district does not exceed a quarter of a mile air-line coverage.

The full-time police department is comprised of the chief of police and a sergeant, who have two police cars, and four police officers. In addition, there are part-time or special police during the summer months. The police budget is about $6000 a year. The township has a valuation of $7,000,000. This is less than $1000 a year per million dollars of valuation. For less than one-tenth of a cent per dollar of property valuation, the township enjoys a radio-equipped police department rendering year-round service night and day.

The radio equipment comprises a 25-watt Motorola transmitter and a superheterodyne receiver at headquarters. Two cars have a 15-watt Motorola transmitter and a superheterodyne receiver each. With these facilities, the following forms of two-way communication are provided:

1. Police station to cars townwide and on occasion many miles beyond.
2. Police station to Harwich police station about 7 miles away and to the county headquarters station at the House of Correction in Barnstable about 20 miles away.
3. Car to car townwide and even beyond. Any part of the township can function car to car, without dead spots.
4. Car to county headquarters station. This hookup is used if the car is operating at night when the police station is unattended. In addition, the car can relay to any fixed or mobile point on Cape Cod through the county station which has 100 per cent coverage of the township.

This system operates on 39,900 kilocycles using amplitude modulation. FM is not used because it is a part of the countywide system built in 1937 before FM became available for police applications.

Sufficient coverage is obtained with a simple antenna on the roof of a two-story building. Greater coverage would be possible if a special antenna and tower were provided; but this is not necessary because of the presence of the county station with twenty-four-hour dispatching service and a 205-foot radio tower utilizing 100 watts power.

The county furnishes free radio maintenance, and the town pays for and replaces the parts required. This cost averages about $2 a month per station for daily service, and in no case does it average over $5 a month. For extended periods there is sometimes no cost other than for the trifling amount of power to operate the equipment.

A police car can reach any part of the township within five minutes on receiving radio instructions.

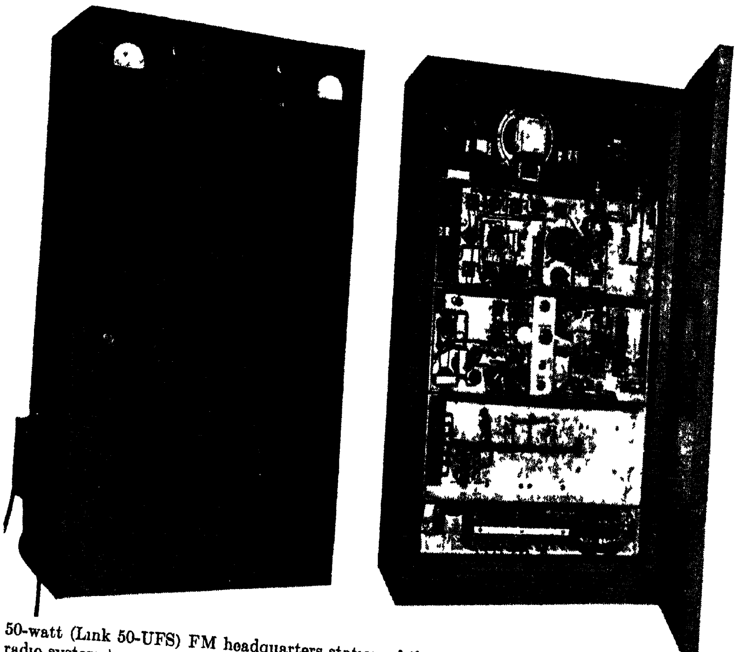
2 Municipal System

The city of South Portland, Maine, a suburb of Portland, comprises twelve square miles and has a population of 17,000. It is the gateway to Portland and to the state of Maine when entering by U.S. Highway 1. Within its borders are several army forts, a vast shipyard, and bulk oil and storage facilities served by water and rail.

The police department comprises fourteen full-time police officers operating three police cars in twenty-four-hour service, one being for the chief of police. Prior to the development of two-way radio facilities, the patrol cars were equipped with one-way radio served by Portland. This was neither efficient nor economical. For cars to answer back, six police-call telephone stations were located at various points in the city and leased from the telephone company at a cost of $600 a year. Two-way radio was adopted because of the inadequacy of one-way radio and the call-telephone expense.

For a cost of less than $1500, not only was the police department completely equipped but also the central fire station and the public works department. The $600 call-box expense more than takes care of the cost of parts and the maintenance of a part-time technician.

This is the first system in Maine to utilize FM. It is on a frequency of 39,180 kilocycles. The equipment was furnished by F. M. Link and consists of the 50-UFS fixed station and the 25-UFM/11-UF mobile station types. Several tests were made in Maine with the mobile units for distances of up to 50 miles two-way. Without any special antenna provisions other than the height of the two-and-one-half story building, the system



50-watt (Link 50-UFS) FM headquarters station of the type used by the South Portland radio system to serve mobile units of Police, Fire, and Public Works Departments.

has coverage equal to several times the maximum air-line distances required either for the fixed or for the mobile stations.

Bangor, the second largest city in the state, adopted the same system, using identical equipment, and many other cities adopted similar facilities by the same or other manufacturers.

In the average city or township, the most difficult area to cover is that closest to police headquarters. The least difficult are the outskirts where open spaces exist to make up for the increased distance of required communication. But the average city can be adequately covered even with minimum power, and no special antenna heights are required other than what the police station building provides.

In the case of South Portland, the fire house was 200 feet across the street from the police station. Rather than duplicate facilities, a control cable runs underground through an existing conduit to the police station, so that an additional loudspeaker and microphone there can function with the same transmitting and receiving equipment as well as antenna system. The expense of connecting the fire house was less than $100 extra.

The fire chief and the public works superintendent have their cars equipped with identical mobile equipment. As a result the system functions two-way as follows:

1. Headquarters to cars anywhere.
2. Cars to headquarters anywhere.
3. Car to car anywhere.
4. Fire station can do the same.
5. Public works car can do the same.

All members of the police, fire, and public works departments having occasion to use the equipment took examinations locally for restricted radiotelephone operator permits. A licensed radiotelephone operator from a local broadcasting station stands by or does the work himself when the transmitters require adjustment or special attention.

3 County System

The Barnstable County police radio system covers the entire Cape Cod area of nearly 80 miles between the Cape Cod Canal and Provincetown. The Massachusetts state legislature authorized the establishment of this system at an annual expenditure of $7000 for equipment, dispatching, and maintenance. Each township was free to join the system by equipping their cars with radio facilities at their own expense, at a cost of $235 each for 10-watt amplitude-modulated equipment. In addition, such towns as cared to do so also provided a low-powered headquarters station so that they could dispatch their own cars directly. The system today covers all the organized police departments and various other agencies with the temporary absence of Provincetown, although it is well able to cover that area also.

Of the fifteen townships comprising Cape Cod, some maintain no regular police station, having only a car, usually privately owned by the police officer or constable. Of the remainder, only two or three man their stations twenty-four hours a day. The county station therefore is invaluable for dispatching service. If the car of any town cannot contact its own station immediately, the county dispatcher handles the message or holds it until the local town police officer returns to the station.

This system is able to communicate via county headquarters with forestry, fire, and state police, and thence through the eight-state teletype system of the state police. Each town is encouraged to maintain its independence by dispatching its own cars. When it does not want to do so, or lacks facilities, or its car is out of town, then the county facilities provides the dispatching service free. The county ordinarily has a staff of four men. Three are dispatchers, and the fourth divides his time between field maintenance and relieving the dispatchers for their day off each week. In

addition, the House of Correction guards can operate the equipment if necessary. The county keeps an inventory of radio parts needed by all units in the system. When any of these parts are expended, they are replaced by ordering from a radio supply house at wholesale prices and are charged to the town that uses them.

100-watt VHF transmitter, Barnstable County Police radio system WRAQ, Maine Station.

The maintenance man visits the fixed stations and all townships periodically for routine checking, such as once a month, unless there is special need for his services. At other times, cars are checked at the county station when on a routine trip to that part of the township.

The county has a 205-foot tower located on a comparatively high level with respect to the adjacent countryside; 100 watts amplitude modulation is used on 39,900 kilocycles. The equipment rendered effective service during both the 1938 and 1944 hurricanes. As a result of the 1938 hurricane experience, a 1500-watt Kohler electric plant, so connected that it automatically comes on and takes over to provide power for radio and lights, is available. It has a large gasoline tank able to keep it operating continuously for many days.

Although FM would work even more efficiently, the system has proved adequate in seven years' continuous service even with low-powered amplitude modulation. The largest township, in which the business center of Hyannis is located, comprises 74 square miles with the police headquarters in one extreme corner of the township. The maximum 12-mile

distance required is covered with the regular equipment of 10 watts at headquarters feeding a coaxial antenna on an 85-foot tower. The township has reported a total annual maintenance cost of $40 in a single year for three mobile units and headquarters for all stations in twenty-four-hour daily service, with each car averaging over 4000 miles a month, according to Harry M. Lawes, the chief of police of Hyannis.

The system started experimentally in 1937 with one fixed and one mobile station. In 1938, it had grown to 12 stations; in 1939, to 22; in 1940, it became 28 stations, and currently totals more than 40 fixed and mobile units. The system also expanded to include the island of Nantucket more than 20 air-line miles away. The units serve police, fire, forestry, welfare, ambulances, sheriffs, House of Correction guards, and emergency users, such as officials of the State Registry of Motor Vehicles.

The maximum air-line distance covered is 28 miles, and the system can also reach New Bedford and beyond and many miles northward beyond Plymouth, despite its early equipment. The area it serves contains 355 miles of coast line and has an assessed valuation exceeding $100,000,000 and a permanent population of over 30,000 with a peak summer population exceeding 100,000.

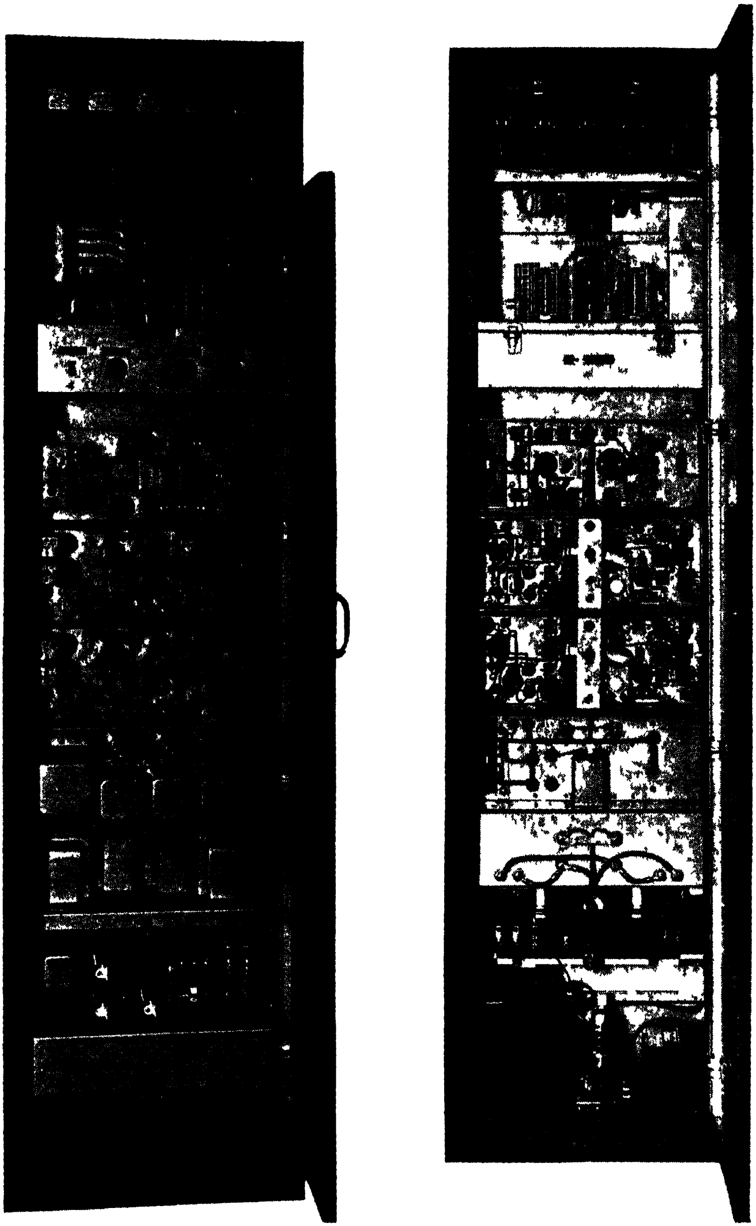
4 State of Connecticut

The Connecticut system was the first FM two-way radio system ever licensed and built in the United States. It was immediately successful and revolutionized two-way radio communication by reason of the many advantages enumerated elsewhere in this book.

Professor Daniel J. Noble of the University of Connecticut, Commissioner Edward J. Hickey, and Radio Engineer Sydney Warner pioneered in its development. Link radio equipment is used throughout the system. No supplementary or complementary radio facilities are used anywhere in the system of medium frequencies as in Maine and Michigan. The system functions 100 per cent on 39,500 kilocycles for the fixed stations and 39,180 kilocycles for the mobile units. By means of a switch on the control box, the mobile stations can switch to the headquarters frequency and operate car to car.

Mobile units requiring maximum coverage utilize roof-top antennas while other units, that dislike roof-top antennas for their unorthodox appearance, utilize antennas mounted at bumper or slightly higher level at the rear of the car.

Each of the eleven troop districts operates a headquarters station transmitting on 39,500 kilocycles with dual receiving equipment for 39,500 kilocycles to receive other headquarters stations and 39,180 kilocycles to receive mobile units. In most cases, hilltops or small mountains a few



Link 250-UFS, 250-watt FM station equipment used at all troop headquarters of the Connecticut State Police radio system

miles away are the remotely controlled transmitting-receiving equipment locations with landline control to the headquarters station.

The state has an excellent overlap of coverage. Any two stations can cover nearly the entire state with only small blank gaps of noncoverage. The various troop districts are also interconnected by a teletype system. The radio facilities are therefore utilized only for handling messages to and from mobile units. The teletype ties in with the eight-state teletype system.

One maintenance man ordinarily takes care of three districts, with his headquarters at one of them. If one station should be off the air for servicing or mishap, an adjacent station serves the area involved and relays information over the teletype. The system could function with less stations, but it would mean that some of the troop districts would not be able to dispatch directly their own cars.

Connecticut contains about 8000 square miles. It is highly industrialized and has a considerable population. It is ordinarily considered poor radio terrain because much of it is hilly and mountainous. However, the number and placement of the stations are such that 100 per cent coverage between cars and fixed points is possible statewide. A radio-equipped car can communicate from Station E across the state to Station B at North Canaan, a distance of about 75 miles air-line and over 100 miles by road. Each car can usually contact two to five fixed stations from any location.

The system including all fixed stations and about 235 mobile units cost approximately $120,000 when built about 1940. A staff of four technicians and one radio engineer maintains the entire system.

5 State of Maine

The Maine State Police radio system was started with no more than an $8000 experimental fund immediately invested in permanent equipment which is still in service. Although Maine comprises nearly 39,000 square miles, about as large as the rest of New England combined, its state police is little more than a skeleton force with each patrolman responsible for several hundred square miles of territory.

The system was organized originally as a joint enterprise of Maine and the National Youth Administration, whereby the state bought the component materials from industry, while the NYA built the equipment from parts and installed it. In addition to furnishing vitally needed communications with little available appropriation at the time, it was intended to furnish practical instruction to a considerable number of defense radio trainees. The plan turned out most successful due to the maximum cooperation and interest of all parties. The system is still expanding to serve

not only the state police but other public agencies desiring or requiring mobile radio facilities.

At the time of its organization, a state police department was considered too large a unit to utilize successfully two-way communication because of limited range. Systems were all one-way on medium frequency. In planning the Maine system, it was decided to utilize two-way facilities on very high frequencies as far as possible and to do it without costly and difficult-to-provide remote control stations. The first consideration was to concentrate on the areas that a car can travel over, namely highways or roads of any kind. This immediately eliminated most of the northwest quadrant of the state. The next consideration was to concentrate on the areas of population. It was found that the barracks were principally located in the southern half of the state and that 25 to 50 mile circles from each barracks could almost solidly cover the southern half of Maine despite the fact that the entire state only had six barracks. It was decided to use dual facilities with 39,900 kilocycles two-way as far as possible, and 1642 kilocycles one-way for the remainder of the state. By placing similar facilities in each district, it was felt that while a car might be unable to pick up a particular station, it would never be so located that it could not pick up at least one station. This turned out to be true.

The typical headquarters station comprises the following:

1. A 200-foot radio tower, performing dual duty, acts as an elevated height for the very-high-frequency coaxial radial antenna on 39,900 kilocycles and as the vertical radiator itself on 1642 kilocycles.
2. A 1642-kilocycle transmitter uses a power output of 100 watts at Wells, 300 watts at Thomaston, and 1000 watts at Augusta. Substations use 25 watts. Additional barrack stations contemplated in the northern part of the state will use about 500 watts at Bangor and Houlton.
3. A 39,900-kilocycle transmitter standardized at 25 watts for AM.
4. Receivers on 1642 kilocycles and 39,900 kilocycles.

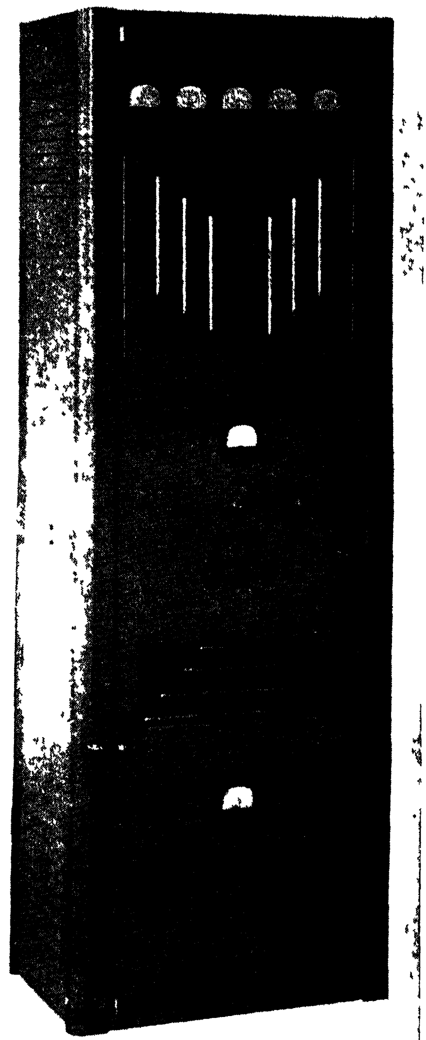
The typical mobile station comprises the following:

1. A 10-watt transmitter on 39,900 kilocycles.
2. Regenerative or superheterodyne receiver on 39,900 kilocycles.
3. Receiver on 1642 kilocycles.

This makes possible the following forms of communication:

1. Headquarters to cars statewide on 1642 kilocycles.
2. Headquarters to cars 25 to 50 miles on 39,900 kilocycles.
3. Cars to headquarters 25 to 50 miles on 39,900 kilocycles.
4. Car to car for various distances up to about 20 miles or more.
5. Headquarters to headquarters statewide on 1642 kilocycles or to adjacent barracks in some cases on 39,900 kilocycles.

The system started too early for the adoption of FM which was still in the planning stage for Connecticut. However, as FM began to demonstrate its superiority in range and intelligibility, the state tested token installations in new districts on the 30 to 40 megacycle band using 50-watt FM equipment. An increase in range of 50 to 100 per cent was immediately obtained, and the state may eventually abandon their AM facilities in favor of FM exclusively, except where required for long-range one-way medium-frequency operations. Even there, it may become feasible to equip the mobile units with loaded antennas and 25 to 50 watt medium-frequency transmitters to answer back. This may give the mobile units erratic transmitting ranges in which skip distances and stations outside the local district will have to be used and then relayed back to the local headquarters. The regenerative receivers have been necessary to maintain the range with AM transmitters, since superheterodynes in many cases pick up too much local noise and have poor signal-to-noise ratios on very high frequencies. As a result, it has been the practice usually to transmit to cars on 1642 kilocycles, except locally, and for cars to answer on 39,900 kilocycles. Car to car, of course, is always conducted on 39,900 kilocycles.



Harvey-Wells FT-100, 100-watt transmitter used to cover outlying cars, and to supplement very high-frequency units. Of medium frequency, this transmitter is used at Wells, Maine.

Night operations on 1642 kilocycles have heretofore been interfered with by Michigan State Police and occasionally by Arkansas on the same frequency; 1642 kilocycles is also difficult to use during

MAINE STATE POLICE FIXED AND MOBILE RADIO FACILITIES

Troop and Barracks Location	FIXED STATION: Transmitter Power 1642 kc	Transmitter Power 39.9 mc	Receiver 1642 kc	Receiver 39.9 mc	Other Frequencies	MOBILE UNITS: Total Cars	With 1642 kc Receivers	2-way Units 39.9 mc	Motor Cycles 1642 kc
Augusta Headquarters	1000 w	25 w	Yes	Yes	1682	7	3	None	None
Troop A Wells	100 w	25 w	Yes	Yes	1682	15	10	5	3
Troop B W Scarboro	25 w	None	Yes	Yes	2422	19	17	5	4
Troop C Augusta	Uses Headquarters Facilities					10	10	7	2
Troop D Thomaston	300 w	25 w	Yes	Yes	—	1	13	11	2
Troop E Bangor	300 w	None	Yes	No	—	14	9	None	None
Troop F Houlton	85 w	None	Yes	No	—	11	6	None	None
Governor and Council	—	—	—	—	—	—	2	1	—
Insurance Commission	—	—	—	—	—	—	3	None	—
Sea and Shore Fisheries, Boothbay Harbor	25 w	None	Yes	No	—	—	—	—	—
Sea and Shore Fisheries, Patrol Boat "Maine"	Mobile 25 w	—	—	—	—	—	1	None	—
New Hampshire State Police	—	—	Yes	—	—	—	—	—	—
Other Agencies and Departments, FBI, FCC, Sheriff, City, etc	—	—	6	—	—	—	8	None	—

lightning or heavy static and along the high-tension lines in parts of Washington and Aroostook counties from Bangor to Eastport to Houlton. These factors tend to point to the likelihood of the state shifting to all FM operation.

Due to great distances and limited budget, the Maine State Police has not been able to afford a connecting teletype service. To get an emergency message through, it utilizes radio facilities to Augusta or Wells, from there contacting the New Hampshire State Police at Concord which is tied in with the eight-state teletype system, being the northern terminus at this time. To facilitate contact with adjacent states, Maine monitors New Hampshire on 1682 kilocycles, while New Hampshire monitors Maine on 1642 kilocycles.

The system also serves other public agencies, such as the Department of Sea and Shore Fisheries at Boothbay Harbor and the patrol boat *Maine* operating along the coast of Maine. The state-owned plane operated by the Inland Fish and Game Commission is also served with two-way communication.

The Department of Sea and Shore Fisheries uses the Harvey-Wells MR-25 marine radiotelephone type of equipment throughout on the following frequencies: (a) 1642 kilocycles to work within the department and with all units of the state police; (b) Boston coastal harbor toll frequency of the Bell Telephone System; and (c) 2670 coast guard NCU distress frequency. The plane of the Inland Fish and Game Commission utilizes 39,900 kilocycles. Because of the excellent horizon when aloft, it obtains remarkable ranges, greatly exceeding those possible by cars on the highway.

Other groups being served or that may eventually be served are the state prison, the Maine Forestry Department, and various local police and sheriffs as they desire. The state maintains repair and maintenance facilities at the headquarters in Augusta and about one man for each 30 mobile units ordinarily in the field.

Personnel having full-time maintenance and repair duties on radio equipment hold second-class or first-class radiotelephone licenses issued by the Federal Communications Commission. All members of the state police who have occasion to operate the equipment hold restricted radiotelephone operator permits. The state police consider their radio facilities equivalent to 25 per cent more men on the road. This is of utmost importance, as they are unlikely to receive the required appropriations for the maximum number of police that could be effectively utilized by a state of such size. Since few large cities or communities in Maine maintain a permanent full-time paid police department, the state police has a task to perform that is comparable to covering a state of even greater area.

Radio has proved to be invaluable, and the officers have thus far exercised exceptional skill in making the most effective use of their facilities. Many otherwise difficult or impossible police tasks have been easily handled as a result of two-way radio communication. Even in remote parts of the state where no local facilities exist, two or more cars have been able to maintain two-way communication with each other. The officers have learned by experience where to locate their cars in order to have extraordinary communication ranges on occasion and hop over large areas where no fixed station facilities exist. The officers have also learned how to point their cars so that the antenna will radiate most effectively in a desired direction to get beyond-horizon ranges two-way. FM equipment using more power and roof-top antennas more ideally placed for propagation and reception of electromagnetic waves will make unnecessary some of these methods for obtaining maximum communication range.

6 State of Michigan

Michigan comprises 57,000 square miles as compared with about 8000 square miles for Connecticut and 39,000 square miles for Maine. Prewar the Michigan State Police operated a one-way system, that is, from headquarters to cars, on 1642 kilocycles. This consisted principally of three powerful transmitters. It comprised 5000-watt transmitters at state headquarters in East Lansing and at Houghton Lake, and a 1000-watt transmitter at Paw Paw. At night this one-way system had a skip distance of about 1000 miles and was picked up by cars of the Maine State Police louder than their own stations. Likewise Michigan was interfered with at night by the Maine State Police medium-frequency stations.

A most progressive step was made when the Michigan State Police adopted frequency modulation in the 30 to 40 megacycle band. This system comprises more than 200 mobile units and more than 45 fixed locations principally at state police posts. Using the same frequencies and co-ordinated with the state police is the extensive State Department of Conservation system employing similar equipment. The fixed stations are so spaced that every state police and conservation car can always communicate back and forth with a fixed station. These fixed stations in turn can communicate with each other and relay messages to and from mobile units statewide. The system was built on the basis of tests and data compiled at the East Lansing Laboratory of the state police, the University of Michigan, the Michigan State College, and the Galvin Manufacturing Company, which supplied the two-way FM equipment used in the system.

The fixed station transmitters use 50 watts output in areas requiring small coverage and 250 watts in areas requiring maximum coverage. Many of the stations operate remote control as much as 5 to 10 miles away from the control point in order to provide ideal coverage. Where more power appeared desirable for a particular area, it was provided by more antenna height. Coaxial type antennas with ⅞-inch coaxial nitrogen-filled transmission lines are employed.

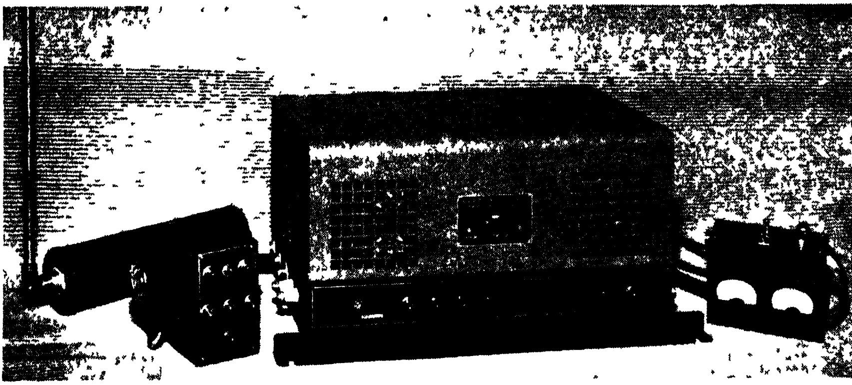
To enable cars to operate two-way as much as 50 miles or more when required, maximum-powered transmitters were provided for the cars, using two 807 tubes in the final stage, rated at 50 watts output. In practice, 60 to 65 watts can be realized by using the receiver power supply to energize the stages preceding the final amplifier tubes. Also to assure maximum uniform coverage, all mobile antennas are quarter-wave roof-top antennas, such as originally used by the Connecticut State Police.

Fixed stations operate on 37,500 kilocycles, while the mobile units transmit on 37,380 kilocycles or 120 kilocycles removed. The car also can switch to 37,500 kilocycles and then transmit as well as receive on the fixed station frequency. When this is done, car-to-car operation is possible up to about 20 miles under favorable conditions. The power drops when cars operate on 37,500 kilocycles as the equipment relies primarily on the different crystal without the circuits being ideally peaked for that frequency. However, the circuits can still respond with considerable effectiveness for several miles.

About a dozen cars operate out of each important fixed station, with less at the smaller stations. These operate on the same frequency, even simultaneously if necessary in their local zones. They do not interfere locally because of the characteristic behavior of FM when one station has two or more times the signal strength of another. The loudest or local station comes through to the cars and erases any trace of the weaker station working in another area.

For administrative purposes, the state is divided into eight districts. Each of these districts has a district headquarters station supervising from one to seven substations. East Lansing can contact these district headquarters stations directly, except that part of Michigan separated by the Great Lakes where Houghton Lake utilizes a radio relay. As in Maine, cars can be reached on either 1642 kilocycles statewide or on very high frequency for local distances.

A two-man tower crew is permanently employed to maintain the 45 radio towers and the coaxial gas-filled transmission lines at all stations. They have a specially designed truck equipped with a winch and tower maintenance items.



Temco Model 25K long-range equipment used by Border Patrol on high frequency band. (Courtesy Transmitter Equipment Manufacturing Co.)

7 Border Patrol

The U.S. Immigration Border Patrol guards the entire Canadian and Mexican borders. Since much of these borders is natural boundary without convenient communication, the ordinary equipment used by police departments is inadequate. Equipment is required that can cover hundreds of miles on occasion.

The Transmitter Equipment Manufacturing Company has produced a Type K equipment which utilizes high-frequency sky-wave performance in addition to local ground-wave coverage. Frequencies are chosen which are capable of ranges up to 3000 miles between mobile units. In addition to having a choice of two frequencies, one being more ideal for day operations (higher in frequency), the other more ideal for night operations (lower in frequency), communication is possible either by telephone or by telegraph. The latter is capable of working under more unfavorable radio-receiving conditions or interference. To operate such equipment with any degree of efficiency in a mobile vehicle, special antenna provisions were necessary. A base-loaded antenna is used.

While ranges beyond horizon are erratic and inconsistent for any time and place, the operating personnel have become very proficient in the best frequency and distance to work. If they find that they must skip by the desired destination, they relay back from a point whose skip is more ideal. The importance of having communication of any kind in the locations where the Border Patrol operates greatly outweighs the inconvenience or crudeness of this method of utilizing mobile sky-wave communications. The personnel are specifically qualified to work this kind of equipment and obtain the necessary performances. Equipment operates on 25 to 50 watts amplitude modulation.

INDEX